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Review paper

Aptian–Albian paleophytogeography and paleoclimatology from Northeastern Brazil sedimentary basins

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ABSTRACT

The eastern, equatorial and interior basins from Northeastern Brazil contain a diverse sedimentary record representative of the events that culminated in the rupture of the Gondwana megacontinent and the genesis of the South Atlantic Ocean. Those events that occurred between the neo-Aptian and neo-Albian (Mid-Cretaceous) were associated with deep climatic changes that, besides involving particular depositional systems from continental to lacustrine-evaporitic-open marine, allowed the development of a wide and diversified vegetation adapted to the new ecological niches then created. Paleobotanical data were analyzed from five intervals defined according to the Brazilian palynological zoning. The middle section of the upper Aptian (P-260) suggests the existence of highlands with cold to hot but dry climate in the interior basins, with high humidity in the interior plains and stressful conditions along the coast. Warmer, but not arid climate prevailed on the east margin, being even hotter and arid on the equatorial margin. The upper Aptian (P-270) is suggestive of highlands in the interior basins and at the eastern and equatorial margins, with hot and humid climate in the interior basins and the eastern margin. The climate would be significantly more arid in the equatorial margin, where coastal evaporitic systems would have been developed. From the neo-Aptian (P-280) the records for the interior basins are not significant. For the eastern and equatorial margin basins would persist the presence of highlands, with a mild climate, with frequent humid, locally hot and arid environments, but not stressful. During early Albian (P-320), the phytogeographic distribution reflects a significant climate change in the east and equatorial margins, with a marked reduction of humidity and reduction or absence of highlands. The climate would have been warm, with increasing aridity and presence of more stressful environments. During mid-Albian (P-330), the highlands would no longer exist on the eastern and equatorial margins, the climate being predominantly hot and dry, but milder on the eastern margin, while on the equatorial margin there would be an increase in aridity from east to west. During the late Albian (P-355 / P-360), in addition to the absence of highlands, the phytogeographic distribution suggests the maintenance of a hot and arid climate, probably representing the hottest climate of the entire studied section.

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1. Introduction

The coastal region of Northeastern Brazil has a series of sedimentary basins dating back to the Late Jurassic–Early Cretaceous. These basins are related to the tectonic movements that fragmented the Gondwana and led to the separation of the South American and African plates and to the genesis of the South Atlantic Ocean (Asmus and Ponte, 1973). These processes also originated some epicontinental basins, now discontinuously represented inside Northeastern Brazil, and therefore called interior basins (Ponte, 1992; Fig. 1). The tectonic processes involved in the breaking apart of Gondwana caused the establishment of a much diversified sedimentary environments passing through an alluvial–fluvial–deltaic–lacustrine to an evaporitic to open marine context from late Aptian to late Albian. This, in turn, caused drastic climatic and ecological changes that were directly reflected in the diversity and abundance of the organisms related to these environments.

Despite the almost common origin, differences in geography, tectonic styles, and source areas, among others, provided a distinct sedimentary filling for these basins, including a variable known fossil content, though diverse and abundant. The integrated study of these different sedimentary sections and interpretation of their depositional environments and evolution in a time–space analysis allows composing a broad, though reliable, paleogeographic scenario spanning the late Aptian–late Albian interval, during which important environmental modifications occurred due to the implantation of the Atlantic proto-ocean.

Among the various fossil groups, plants, and in particular, palynomorphs provide, in addition to biostratigraphical data, valuable information about the depositional environments and paleoclimates, especially when integrated to sedimentary facies data (Martínez et al., 2008).

Climate reconstruction based on sporomorphs records is based on the premise that, since the distribution of vegetation is largely influenced by the climate, it is possible to use this distribution to reconstruct the paleoclimatic conditions prevailing at the time the sediments that contain these sporomorphs were deposited (Bradley, 2013). Thus, stratigraphic and geographical changes in sporomorphs assemblages would register changes in the composition of the vegetation, which, in turn, provide information about changes in species distribution and climate (Jackson, 1994). It is due to the similarities expected in changing the sporomorphs assemblages in geographically distinct but relatively close areas, that it becomes possible to establish a stratigraphic zoning based on these assemblages, indicating contemporaneity or not between geographically separate strata, one of the basic precepts for biostratigraphy. This is possible due to the following factors (Bradley, 2013):

1. Sporomorphs have morphological characteristics specifical of a particular family, genus or species of plant.
2. They are produced in large amounts by plants mainly wind-pollinated and widely distributed from these sources.
3. They are extremely resistant to decay in some sedimentary environments.
4. They reflect the natural vegetation at the time of deposition.

However, many variables are involved in the deposition of palynomorphs (Traverse, 1994; Tyson 1995; Batten, 1996), being quite complex the understanding of its distribution and the extent of its dispersion.

Different carriers (e.g., wind/water) can select/concentrate forms (Holmes, 1994). This implies that at a stratigraphic sequence, relative changes in types of sporomorphs may be due to hydrological and sedimentological changes at the sampling site. As this author asserts, it should be important to differentiate local palynomorphs (few tens of meters from the source), extralocal (a few hundred meters from the source) and regional (deposited more than a few hundred meters from its origin). However, experimental data (e.g., Streel and Richelot, 1994) demonstrated that the local vegetation provides most of the palynomorphs content from one location and that the contribution of pollens and spores carried by the wind is less significant than the local pollen "rain".

The spatial work's scale also highlights other susceptibilities related to the question of under/over sporomorphs representativeness. It was observed that in modern environments, some taxa, in particular, were consistently under/overrepresented in sporomorphs assemblages (Bradshaw, 1994; Jackson, 1994). Bradley (2013), e.g., noted that sporomorphs with low levels of dispersion are locally recorded with high sensitivity for some sampled sites, but their records may be lost on a wider scale. On the other hand, a very productive and dispersed taxon can provide more regional evidences on climatic and terrain conditions (Jackson, 1994).

In addition, local sedimentary factors affect the local concentrations of palynomorphs. Dimensions of the sedimentary basin, direction and wind regime, extension, flowrate and direction of waterways, topography, among other factors, will differentially influence the transport, dispersion, and accumulation of sporomorphs (Jackson, 1994; Traverse, 1994). Where possible, the use of templates (e.g., Prentice, 1985) simplifies an extremely complex set of processes that vary spatially and temporally. However, in most cases, this cannot be established in the fossil record.

Thus, for a paleophytogeographic analysis, some basic assumptions should be taken into consideration for the interpretation of an area:

1. The sporomorphs assemblage should be related to existing vegetation on the spatial scale of interest (Jackson, 1994).
2. The spatial variation in the sporomorphs assemblages should reflect the spatial variation in the vegetation composition (Jackson, 1994).
3. The in situ variations in sporomorphs assemblages is considerably smaller than the variation between different sites attributed to the variation of vegetation (Jackson, 1994).
4. The climatic requirements from the closest modern analogs of fossils sporomorphs assemblages are similar (Bradshaw, 1994).
5. There is a greater probability that the most common and abundant forms are registered even with a small number of analysis.

However, some questions deserve attention in these interpretations:

1. Not all temporal and spatial changes in vegetation are necessarily due to climate issues (e.g., destruction by fire, insect infestation; Jackson, 1994; Bradley, 2013).
2. There may be changes in the factors that favor the accumulation and preservation of palynomorphs (Bradley, 2013).
3. In a very restricted temporal or spatial scale, the information obtained by studying the sporomorphs will be dominated by short-term aspects (synoptic scale) affecting their dispersion, or by local factors that affect plant growth (Bradley, 2013).
4. Not all basins with published records exhibit the same sampling density that can reliably cover their sporomorphs content – some basins are further studied than others.
5. Most of the records are essentially a qualitative approach to the sporomorphs content, preventing interpretations based on the predominant forms (lack of quantitative analysis).
6. For many taxa, their botanical affinities are unknown, difficulting or precluding environmental reconstructions based on their records (Bradshaw, 1994) and even in cases of alleged affinities, there will be always a degree of uncertainty in the inferences arising therefrom.

However, selecting the correct spatial–temporal scale, studies on sporomorphs can isolate the most important climatic data from non-climatic noises (Bradshaw, 1994; Bradley, 2013). Furthermore, the characteristics of sporomorphs preserved at each location will guide their application possibilities,

Fig. 1. Brazilian sedimentary basins with emphasis on the three sets of the studied basins (equatorial-margin, east-margin, and interior basins). Bold names represent the basins that present published paleobotanical data used in this study; white-filled names are basins without any paleobotanical published data.

determining the detail degree and reliability of the inferred reconstructions (Bradshaw, 1994).

Unfortunately, a significant portion of palynomorph records existing for the Brazilian sedimentary basins is data-proprietary from the major hydrocarbon exploration companies, and the published data are significantly fewer than the amount of existing data. The scarcity of published data and their spatial heterogeneity hinder more realistic correlations.

2. Objectives

The present study aims to rebuild the climatic and paleoecologic scenario that existed in the marginal and interior basins of Northeast Brazil during the Aptian–Albian (the final part of the Early Cretaceous) interval based on paleobotanic records, particularly related to pollens and spores.

The Aptian–Albian interval from the Brazilian marginal basins was selected as it contains the largest available data set for different basins, although without homogeneous distribution. It is one of the intervals of more drastic ecological, climatic, sedimentary and tectonic changes to the Brazilian marginal basins which are related to the rupture of Gondwana and implementation of the South Atlantic Ocean.

3. Material and methods

For the purposes of this study, the selected basins were grouped into three sets (Fig. 1):

1. **The east-margin basins**, encompassing Cumuruxatiba (Mariricu and Regência formations), Camamu (Algodões and Taipus Mirim formations), Recôncavo (Marizal Formation), Sergipe-Alagoas (Maceió, Muribeca, Riachuelo, and Cabo formations – this last one in the Cabo Sub-basin) and Tucano (Marizal Formation).
2. **The equatorial-margin basins** – Potiguar (Alagamar, Açu and Ponta do Mel formations), Ceará (Paracuru, Mundaú, and Ubarana formations), Parnaíba (Itapecuru and Grajaú formations), Barreirinhas and Pará-Maranhão (Canárias and Caju groups), Ilha Nova, São Luís. and Bragança-Viseu (Grajau, Codó and Itapecuru formations).
3. **The interior basins** – Jatobá (Marizal Formation), Araripe (Santana Formation) and Icó (Lima Campos Formation sensu Mabesoone and Campanha, 1974; Lima, 1990).

The database used in this study was constructed by compilation from the palynological and megafloristic aptian–albian data available in the literature for these selected Brazilian basins. Despite extensive research, it is certainly possible that

some data have not been considered. For all genera retrieved from each basin, it was also recovered references to the stratigraphic units they came from, their biostratigraphic zones and geographical origin. Data were organized into five lithostratigraphic intervals, according to the Brazilian palynological zonation established by Regali et al. (1974, 1975), modified by Regali (1987c, 1989, 1995) and Regali and Gonzaga (1985; Fig. 2): middle section of the upper Aptian (palynomorph zone P-260); top of the upper Aptian (P-270 zone); uppermost upper Aptian (P-280 zone); lower Albian (P-320 zone); middle Albian (P-330 zone) and upper Albian (including zones P-355 and P-360).

For the purposes of this study, those taxa lacking records in a certain stratigraphic range of a particular basin, but with occurrences at intervals under- and overlying these "hiatuses" were considered likely to be found along all the range in question. They are cited in the text as an extension of these occurrences.

In order to support the data interpretation, it was recovered, based on specific literature, the taxonomic affinity to the family level assigned to each registered genera and their paleoecological affinities. For grouping purposes, five major divisions were considered, even if some of them are paraphyletic: Gymnospermae, Angiospermae, Pteridophyta, Lycopodiophyta, and Bryophyta. The botanical affinities (Fig. 3) used were obtained from the following works: Selling, 1944; Couper, 1953; Thomson and Pflug, 1953; Balme, 1957; Pierce, 1961; Pocock and Jansonius, 1961; Dettmann, 1963; Van der Hammen, 1963; Stover, 1964; Gamerro, 1965; Jardiné and Magloire, 1965; Srivastava, 1967; Germeraad et al., 1968; Nair, 1968; Jain, 1969; Pocock, 1970; Harris, 1971; Singh, 1971; Van Konijnenburg-Van Cittert, 1971; Srivastava, 1972; Herngreen, 1973, 1974; Regali et al., 1974, 1975; Ziembinska-Tworzydlo, 1974; Boltenhagen, 1975a, b; Potonié, 1975; Frederiksen, 1980; Wingate, 1980; Dettmann, 1981; Alvin, 1982; Skog, 1982; Lorente, 1986, in Valero, 2014; Pocock and Vasanthy, 1988; Retallack and Dilcher, 1988; Van Erve and Mohr, 1988; Bussell and Mildenhall, 1990; Doyle et al., 1990; Takahashi and Sugiyama, 1990; Taylor, 1990; Wang and Wang, 1990, in Kustatscher et al., 2010; Doyle and Hotton, 1991; Dettmann and Clifford, 1992; Nichols and Brown, 1992; Pais, 1992; Kubitzki et al., 1993; Osborn et al., 1993; Stewart and Rothwell, 1993; Dettmann, 1994; Upchurch Jr. et al. 1994; Balme, 1995; Agarwal et al., 1996; Dino, 1996; Takahashi, 1997; Abbink, 1998, in Kustatscher et al., 2010; Archangelsky and Seoane, 1998; Dino et al., 1999; Doyle, 1999; Graham et al., 2000; Carvalho, 2001; Schrank, 2001; Schneider et al., 2002; Marchant et al., 2002; Mitra, 2002; Mohr and Rydin, 2002; Mohr and Eklund, 2003; Petersen et al., 2003; Rydin et al., 2003; Mohr and Bernardes-de-Oliveira, 2004; Anderson et al., 2005; Del Fueyo and Archangelsky, 2005; Dilcher et al., 2005; Archangelsky and Archangelsky, 2006; Martill et al., 2007; Nagalingum, 2007; Archangelsky, 2008; Mohr et al., 2008; Taylor et al., 2008; Deaf, 2009; Gomez et al., 2009; Scafati et al., 2009; Bankhole, 2010; Bell et al., 2010; Jaramillo et al., 2011; Kustatscher et al., 2010; Mander et al., 2010; Villanueva-Amadoz et al., 2010; El Beialy et al., 2011; Friis et al., 2011; Kunzmann et al., 2011; Raine et al., 2011; Meyen, 2012; Petersen and Lindström, 2012; Biagolini et al., 2013; Hochuli and Feist-Burkhardt, 2013; Legrand et al., 2013; Ricardi-Branco et al., 2013; Vallati, 2013; Valero, 2014; Villanueva-Amadoz et al., 2014; Zhang et al., 2014; Halamski et al., 2016; Marmi et al., 2016; Sá and Carvalho, 2017; Churchill et al., 2017. Genera with an indefinite affinity (*incertae sedis*) was not used, except for the Coniferae *incertae sedis Complicatisaccus cearensis*, a species commonly recorded for the upper Aptian from Northeastern Brazil and, until recently, the guide-form for the P-280 palynomorph biostratigraphic zone (Regali, 1989; Carvalho, 2001). When more than a botanical affinity was found, we adopted the most recent proposal.

The stratigraphic context for the various analyzed intervals follows Santos et al., 1995; Rodovalho et al., 2007 (Cumuruxatiba Basin); Netto et al., 1995; Caixeta et al., 2007 (Camamu); Feijó, 1995b; Souza-Lima, 2006; Campos Neto et al., 2007 (Sergipe-Alagoas); Caixeta et al., 1995; Costa et al., 2007a, b; Silva et al., 2007 (Recôncavo, Tucano, and Jatobá); Araripe and Feijó, 1995; Pessoa Neto et al., 2007(Potiguar); Beltrami et al., 1995; Condé et al., 2007 (Ceará); Lima et al., 1995; Zalán, 2007 (Bragança-Viseu, São Luís, and Ilha Nova); Feijó, 1995a; Trosdtorf Jr. et al., 2007 (Barreirinhas); Brandão and Feijó, 1995; Soares et al., 2007 (Pará-Maranhão); Góes and Feijó, 1995; Vaz et al., 2007 (Parnaíba); Assine, 2007 (Araripe); Mabesoone and Campanha, 1974; Lima, 1990 (Icó).

For each stratigraphic interval, it was built a table relating the familes (eventually order) occurrences by basin (Tables 1–6). The paleoecological data were used for generating schematic profiles (adapted from Martínez et al., 2008) summarizing the preferred family/order distribution (Fig. 3) in accordance with simplified environmental subdivisions. These were: highlands, lowlands (interior and coastal plains), dry or humid areas (margins of freshwater bodies – rivers, lakes – and the coastal lacustrine/marine region), and type of land (saline, waterlogged, dry). They were then associated with the lithostratigraphic units defined for the various basins. The paleoecological and paleoclimatic inferences are summarized in Tables A.1–A.5 (Appendix A).

CHRONOSTRATIGRAPHY			SUPERZONE		ZONE	
CRETACEOUS	ALBIAN	UPPER	*Elaterosporites protensus*[1]	P-350 (*pars*)	*Elaterosporites protensus*[1]	P-360
			Elaterosporites protensus[1]	P-350 (*pars*)	*Classopolis echinatus*[2]	P-355
		MID	*Stellatopollis barghoorni*[3]	P-300	*Steevesipollenites alatiformis*[1]	P-330
		LOWER	*Stellatopollis barghoorni*[3]	P-300	*Elateropollenites jardinei*[1]	P-320
	APTIAN (*pars*)	UPPER	*Exesipollenites tumulus*[1]	P-200 (*pars*)	*Complicatisaccus cearensis*[4]	P-280
			Exesipollenites tumulus[1]	P-200 (*pars*)	*Sergipea variverrucata*[1]	P-270
			Exesipollenites tumulus[1]	P-200 (*pars*)	*Inaperturopollenites turbatus*[1]	P-260

Fig. 2. Biostratigraphic zoning of the upper Aptian–upper Albian interval for the eastern, equatorial and interior basins of Northeast Brazil (adapted from Regali et al., 1974, 1975[1]; Regali, 1995[2]; Regali and Gonzaga, 1985[3] and Regali, 1987c[4]).

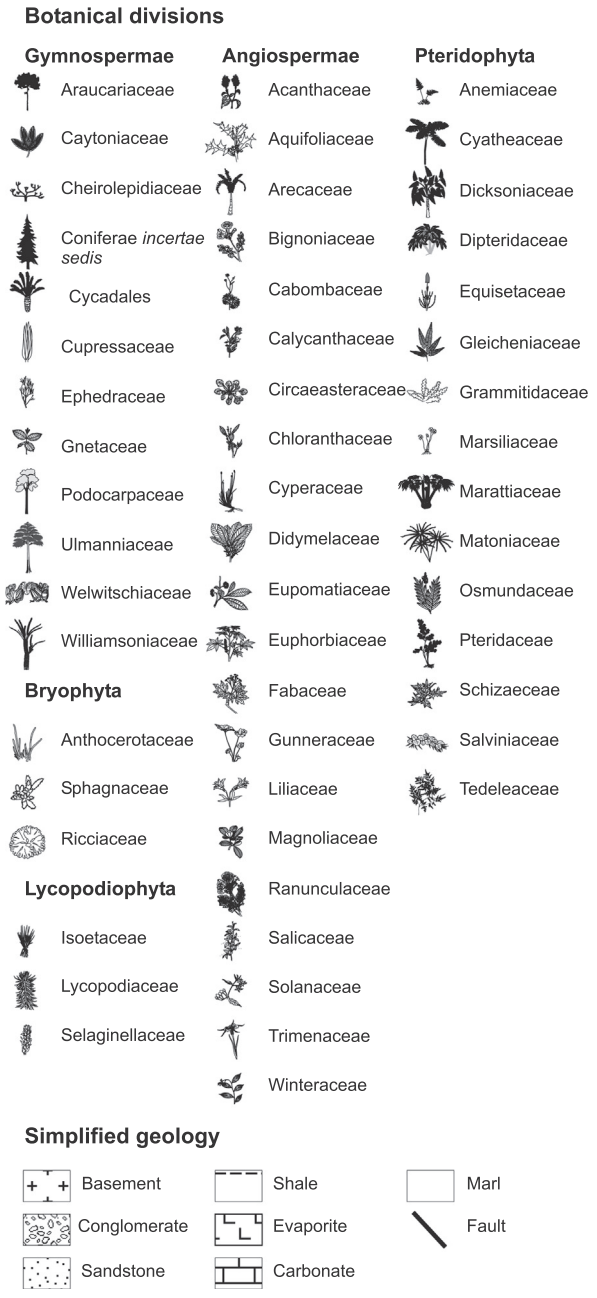

Fig. 3. Graphical representation for the families/orders whose affinities were established for the genera used in this study (not to scale). These taxa were grouped into five major botanical divisions considered for simplification purposes in this study. These drawings, as well as the simplified geology, were used on the paleophytogeographic profiles from Figs. 4 to 8.

Table 1
Geographical distribution of the families/orders assigned to the middle upper Aptian (P-260 zone).

	Family/Order	Cumuruxatiba	Camamu	Recôncavo	Sergipe-Alagoas	Tucano	Jatobá	Araripe	Icó	Potiguar	Ceará	Parnaíba	Barrerinhas	Ilha Nova	São Luís	Pará-Maranhão	Bragança-Viseu
Gymnospermae	Araucariaceae				x				x								
	Caytoniaceae		x		x					x	x	x	x				
	Cheirolepidiaceae								x								
	Coniferae *i. sedis*		x		x						x		x			x	
	Cupressaceae		x		x	x			x	x	x		x			x	
	Cycadadales								x								
	Ephedraceae	x	x							x			x				
	Gnetaceae		x		x	x		x			x	x	x				x
	Podocarpaceae								x								
	Ulmanniaceae																
	Welwitschiaceae																
	Williamsoniaceae																
Angiospermaee	Acanthaceae																
	Aquifoliaceae																
	Arecaceae																
	Aristolochiaceae																
	Bignoniaceae																
	Cabombaceae																
	Calycanthaceae																
	Chloranthaceae																
	Circaeasteraceae																
	Cyperacea																
	Didymelaceae																
	Euphorbiaceae																
	Eupomatiaceae																
	Fabaceae																
	Gunneraceae																
	Liliaceae																
	Magnoliaceae				x												
	Ranunculaceae																
	Salicaceae																
	Trimeniaceae																
	Winteraceae				x	x					x						
Pteridophyta	Anemiaceae				x				x								
	Cyatheaceae								x								
	Dicksoniaceae								x								
	Dipteridaceae																
	Equisetaceae																
	Grammitidaceae																
	Gleicheniaceae																
	Marattiaceae								x								
	Marsileaceae																
	Matoniaceae																
	Osmundaceae								x								
	Pteridaceae																
	Salviniacea								x								
	Schizaeceae	x			x				x	x	x						
	Tedeleaceae																
Lycopodiophyta	Isoetaceae																
	Lycopodiaceae								x								
	Selaginellaceae								x								
Bryophyta	Anthocerotaceae																
	Sphagnaceae																
	Ricciaceae																

Table 2
Geographical distribution of the families/orders assigned to the top of the upper Aptian (P-270 zone).

	Family/Order	Cumuruxatiba	Camamu	Recôncavo	Sergipe-Alagoas	Tucano	Jatobá	Araripe	Icó	Potiguar	Ceará	Parnaíba	Barrerinhas	Ilha Nova	São Luís	Pará-Maranhão	Bragança-Viseu
Gymnospermae	Araucariaceae				x		x	x									
	Caytoniaceae		x		x			x		x	x	x	x				
	Cheirolepidiaceae				x	x	x	x					x		x		
	Coniferae *i. sedis*		x		x						x		x				
	Cupressaceae				x		x	x		x							
	Cycadales				x		x	x		x					x		
	Ephedraceae				x		x	x		x	x				x		
	Gnetaceae		x		x	x	x	x		x	x	x	x	x	x	x	x
	Podocarpaceae		x		x	x	x	x		x	x	x	x				x
	Ulmanniaceae							x									
	Welwitschiaceae							x									
	Williamsoniaceae							x									
Angiospermae	Acanthaceae				x					x							
	Aquifoliaceae				x												
	Arecaceae							x									
	Bignoniaceae									x							
	Cabombaceae							x									
	Calycanthaceae							x									
	Chloranthaceae				x			x									
	Circaeasteraceae							x									
	Cyperaceae				x			x									
	Didymelaceae																
	Euphorbiaceae				x		x	x							x		
	Eupomatiaceae							x									
	Fabaceae							x		x							
	Gunneraceae				x			x		x					x		
	Liliaceae				x					x	x		x				
	Magnoliaceae				x		x										
	Ranunculaceae							x									
	Salicaceae				x			x									
	Trimeniaceae							x									
	Winteraceae				x	x		x			x				x		
Pteridophyta	Anemiaceae				x		x	x									x
	Cyatheaceae						x	x									
	Dicksoniaceae							x									
	Dipteridaceae							x									
	Equisetaceae					x	x	x									
	Grammitidaceae						x										
	Gleicheniaceae				x			x									
	Marattiaceae																
	Marsileaceae				x			x									x
	Matoniaceae							x									
	Osmundaceae						x	x									
	Pteridaceae							x									
	Salviniacea							x									
	Schizaeaceae				x		x	x									x
	Tedeleaceae																
Lycopodiophyta	Isoetaceae							x									
	Lycopodiaceae				x		x	x									
	Selaginellaceae				x		x	x									
Bryophyta	Anthocerotaceae				x			x									
	Sphagnaceae							x									
	Ricciaceae							x									

Table 3
Geographical distribution of the families/orders assigned to the uppermost upper Aptian (P-280 zone).

	Family/Order	Cumuruxatiba	Camamu	Recôncavo	Sergipe-Alagoas	Tucano	Jatobá	Araripe	Icó	Potiguar	Ceará	Parnaíba	Barrerinhas	Ilha Nova	São Luís	Pará-Maranhão	Bragança-Viseu
Gymnospermae	Araucariaceae				x						x		x		x		x
	Caytoniaceae		x		x					x	x	x	x		x		x
	Cheirolepidiaceae																
	Coniferae *i. sedis*		x		x	x				x	x	x	x		x		x
	Cupressaceae				x					x	x		x		x		x
	Cycadales									x							
	Ephedraceae				x						x		x		x		
	Gnetaceae				x						x		x		x		x
	Podocarpaceae		x		x	x				x	x	x	x		x		x
	Ulmanniaceae																
	Welwitschiaceae																
	Williamsoniaceae																
Angiospermaee	Acanthaceae				x					x							
	Aquifoliaceae																
	Arecaceae				x												
	Bignoniaceae									x							
	Cabombaceae																
	Calycanthaceae																
	Chloranthaceae				x						x		x				
	Circaeasteraceae																
	Cyperaceae																
	Didymelaceae																
	Euphorbiaceae				x								x		x		
	Eupomatiaceae																
	Fabaceae				x					x	x		x				
	Gunneraceae				x					x	x		x				
	Liliaceae				x					x	x		x				
	Magnoliaceae				x						x		x				
	Ranunculaceae																
	Salicaceae																
	Trimeniaceae				x						x		x		x		x
	Winteraceae				x	x		x			x		x				
Pteridophyta	Anemiaceae				x												
	Cyatheaceae												x				
	Dicksoniaceae				x												
	Dipteridaceae																
	Equisetaceae																
	Grammitidaceae																
	Gleicheniaceae				x												
	Marattiaceae																
	Marsileaceae				x						x		x				x
	Matoniaceae				x						x		x		x		x
	Osmundaceae				x						x		x				
	Pteridaceae																
	Salviniacea																
	Schizaeaceae				x						x		x				
	Tedeleaceae				x												
Lycopodiophyta	Isoetaceae																
	Lycopodiaceae				x						x		x		x		
	Selaginellaceae																
Bryophyta	Anthocerotaceae				x						x		x				
	Sphagnaceae				x												
	Ricciaceae																

Table 4
Geographical distribution of the families/orders assigned to the lower Albian (P-320 zone).

	Family/Order	Cumuruxatiba	Camamu	Recôncavo	Sergipe-Alagoas	Tucano	Jatobá	Araripe	Icó	Potiguar	Ceará	Parnaíba	Barrerinhas	Ilha Nova	São Luís	Pará-Maranhão	Bragança-Viseu
Gymnospermae	Araucariaceae				x					x		x	x		x		
	Caytoniaceae		x		x					x	x	x	x				
	Cheirolepidiaceae				x							x					
	Coniferae *i. sedis*																
	Cupressaceae									x		x					
	Cycadales				x					x							
	Ephedraceae	x	x								x	x	x	x	x	x	
	Gnetaceae	x	x		x			x		x	x	x	x	x	x	x	x
	Podocarpaceae												x				
	Ulmanniaceae																
	Welwitschiaceae																
	Williamsoniaceae																
Angiospermae	Acanthaceae									x							
	Aquifoliaceae																
	Arecaceae											x					
	Aristolochiaceae																
	Bignoniaceae									x							
	Cabombaceae																
	Calycanthaceae																
	Chloranthaceae																
	Circaeasteraceae																
	Cyperaceae																
	Didymelaceae																
	Euphorbiaceae									x		x	x		x		x
	Eupomatiaceae																
	Fabaceae				x					x	x		x				
	Gunneraceae									x		x					
	Liliaceae											x					
	Magnoliaceae																
	Ranunculaceae																
	Salicaceae																
	Trimenaceae				x						x	x	x				
	Winteraceae				x			x		x	x	x	x		x		x
Pteridophyta	Anemiaceae											x					
	Cyatheaceae																
	Dicksoniaceae																
	Dipteridaceae																
	Equisetaceae																
	Grammitidaceae																
	Gleicheniaceae																
	Marattiaceae																
	Marsileaceae				x							x	x		x		x
	Matoniaceae																
	Osmundaceae											x					
	Pteridaceae																
	Salviniacea																
	Schizaeaceae																
	Tedeleaceae																
Lycopodiophyta	Isoetaceae																
	Lycopodiaceae				x						x	x	x				
	Selaginellaceae																
Bryophyta	Anthocerotaceae																
	Sphagnaceae																
	Ricciaceae																

Table 5
Geographical distribution of the families/orders assigned to the middle Albian (P-330 zone).

	Family/Order	Cumuruxatiba	Camamu	Recôncavo	Sergipe-Alagoas	Tucano	Jatobá	Araripe	Icó	Potiguar	Ceará	Parnaíba	Barrerinhas	Ilha Nova	São Luís	Pará-Maranhão	Bragança-Viseu
Gymnospermae	Araucariaceae									x			x		x		
	Caytoniaceae		x		x					x	x	x	x				
	Cheirolepidiaceae				x										x		
	Coniferae *i. sedis*																
	Cupressaceae									x							
	Cycadales									x							
	Ephedraceae												x		x		
	Gnetaceae	x			x					x		x	x	x	x		x
	Podocarpaceae												x				
	Ulmanniaceae																
	Welwitschiaceae																
	Williamsoniaceae																
Angiospermae	Acanthaceae									x							
	Aquifoliaceae																
	Arecaceae												x				
	Aristolochiaceae																
	Bignoniaceae									x							
	Cabombaceae																
	Calycanthaceae																
	Chloranthaceae																
	Circaeasteraceae																
	Cyperaceae																
	Didymelaceae																
	Euphorbiaceae									x					x		x
	Eupomatiaceae																
	Fabaceae				x					x	x		x				
	Gunneraceae									x							
	Liliaceae																
	Magnoliaceae																
	Ranunculaceae																
	Salicaceae																
	Trimenaceae				x						x		x				
	Winteraceae				x			x		x	x		x				
Pteridophyta	Anemiaceae																
	Cyatheaceae																
	Dicksoniaceae																
	Dipteridaceae																
	Equisetaceae																
	Grammitidaceae																
	Gleicheniaceae																
	Marattiaceae																
	Marsileaceae				x								x		x		x
	Matoniaceae																
	Osmundaceae																
	Pteridaceae																
	Salviniacea																
	Schizaeaceae																
	Tedeleaceae																
Lycopodiophyta	Isoetaceae																
	Lycopodiaceae				x						x		x				
	Selaginellaceae																
Bryophyta	Anthocerotaceae																
	Sphagnaceae																
	Ricciaceae																

Table 6
Geographical distribution of the families/orders assigned to the upper Albian (P-355 to P-360 zones).

	Family/Order	Cumuruxatiba	Camamu	Recôncavo	Sergipe-Alagoas	Tucano	Jatobá	Araripe	Icó	Potiguar	Ceará	Parnaíba	Barrerinhas	Ilha Nova	São Luís	Pará-Maranhão	Bragança-Viseu
Gymnospermae	Araucariaceae				x					x			x		x		
	Caytoniaceae																
	Cheirolepidiaceae	x	x		x			x		x	x	x	x	x	x		x
	Coniferae *i. sedis*																
	Cupressaceae									x							
	Cycadales									x							
	Ephedraceae		x		x					x	x		x		x		x
	Gnetaceae	x	x		x			x		x	x	x	x	x	x		x
	Podocarpaceae												x				
	Ulmanniaceae																
	Welwitschiaceae				x												
	Williamsoniaceae																
Angiospermae	Acanthaceae									x							
	Aquifoliaceae																
	Arecaceae												x				
	Aristolochiaceae																
	Bignoniaceae																
	Cabombaceae																
	Calycanthaceae																
	Chloranthaceae																
	Circaeasteraceae																
	Cyperaceae																
	Didymelaceae		x		x					x	x		x				
	Euphorbiaceae																
	Eupomatiaceae																
	Fabaceae		x		x					x	x		x				
	Gunneraceae																
	Liliaceae																
	Magnoliaceae				x												
	Ranunculaceae																
	Salicaceae																
	Trimenaceae		x		x					x	x		x				
	Winteraceae				x			x		x	x		x				
Pteridophyta	Anemiaceae																
	Cyatheaceae																
	Dicksoniaceae																
	Dipteridaceae																
	Equisetaceae																
	Grammitidaceae																
	Gleicheniaceae																
	Marattiaceae																
	Marsileaceae												x				x
	Matoniaceae																
	Osmundaceae																
	Pteridaceae																
	Salviniacea																
	Schizaeaceae																
	Tedeleaceae																
Lycopodiophyta	Isoetaceae																
	Lycopodiaceae		x		x					x	x		x				
	Selaginellaceae																
Bryophyta	Anthocerotaceae		x		x					x	x		x				
	Sphagnaceae																
	Ricciaceae																

4. Results (Data analysis)

4.1. Middle upper Aptian (P-260)

The middle portion of the upper Aptian corresponds to the zone defined by the presence of *Inaperturopollenites turbatus* (Angiospermae, Cupressaceae; P-260 zone) and the absence of *Tucanopollis crisopolensis* (Angiospermae, Aristolochiaceae) being assignable to the middle portion of the Gargasian, or middle portion of the Alagoas local stage. It is a much-understudied interval, although diversely represented in the east-margin basins (Camamu, Sergipe-Alagoas, and Tucano), equatorial-margin basins (Potiguar, Ceará, Barreirinhas, and Pará-Maranhão) and in only one of the interior basins (Icó).

The Icó and Sergipe-Alagoas basins are those with the most diverse record (Regali et al., 1974, 1975; Lima, 1990; Regali and Silva Santos, 1999; Lima Filho and Silva-Santos, 2001*in*Tomé et al., 2006; Table 1). The records for the equatorial-margin basins are scattered. The studied palynomorphs were obtained from the Maceió (Sergipe-Alagoas Basin) and Cabo formations (Cabo Sub-basin, northern portion of the Sergipe-Alagoas Basin), from sections assigned to the uppermost portion of the Lima Campos Formation (Icó Basin; Mabesoone and Campanha, 1974; Lima, 1990) and Alagamar (lower portion, Potiguar Basin), Mundaú (Ceará Basin) and Grajaú-Codó formations (Parnaiba, Barreirinhas, and Pará-Maranhão basins). An alluvial–fluvial–lacustrine depositional system was interpreted for these units (Feijó, 1995a, b; Condé et al., 2007; Pessoa Neto et al., 2007; Vaz et al., 2007; Trosdtorf Jr. et al., 2007).

In this interval, the Gymnospermae and Pteridophyta prevail over the Angiospermae. It is significant the diversity of Pteridophyta in Icó Basin (Lima, 1990) and the under-representation of Angiospermae in all basins. The Angiospermae are restricted to the family Winteraceae with a single genus, *Afropollis*, recorded only in the Sergipe-Alagoas, Ceará, and Tucano basins (Regali, 1987b, 1989), and to the Magnoliaceae *Trifossapollenites*, recorded only in the Cabo Sub-basin (Sergipe-Alagoas Basin; Lima Filho and Silva-Santos, 2001 in Tomé et al., 2006). The Gymnospermae and Pteridophyta diversities show that the climatic and ecological conditions favored the development of this group at this interval. The Icó Basin exhibits the greatest paleobotanic diversity, though without any currently known occurrences for the Angiospermae, a still-expanding group, which had its appearance in the geological record probably from the Hauterivian (Doyle et al., 1982), but recorded for Sergipe-Alagoas and other basins at this interval.

The Gnetaceae were the dominant Gymnospermae at this interval, represented by various species from the genus *Sergipea* (Regali, 1987a). They are followed by the Cupressaceae represented by *Uesuguipollenites callosus*, *Exesipollenites tumulus*, *Inaperturopollenites turbatus*, *I. simplex*, *Perinopollenites elatoides*, and *Spheripollenites psilatus*, but with different records for each basin. The Caytoniaceae, with *Vitreisporites pustulosus* (Camamu, Sergipe-Alagoas, Potiguar, Ceará, and Parnaiba Barreirinhas basins), followed by the Coniferae *incertae sedis Complicatisaccus cearensis*, have an extensive record (Camamu, Sergipe-Alagoas, Ceará, Barreirinhas, and Pará-Maranhão basins). Other families (Araucariaceae, Cheirolepidiaceae, and Podocarpaceae) and Cycadales are distinctly represented only at the Sergipe-Alagoas and Icó basins. On the other hand, Ephedraceae, represented uniquely by *Pentapsis valdiviae*, is restricted to the Cumuruxatiba, Camamu, Potiguar, and Barreirinhas basins.

The extensive presence of Cupressaceae for almost all basins is indicative of hot, dry climate (Deaf, 2009). The Araucariaceae are represented by *Araucariacites australis* in the Sergipe-Alagoas and Icó basins. The Coniferae *incertae sedis*, represented by *Complicatisaccus cearensis*, were recorded for Camamu, Sergipe-Alagoas, Ceará, and Barreirinhas basins. The Caytoniaceae are represented in Camamu, Sergipe-Alagoas, Potiguar, Ceará, Parnaiba, and Barreirinhas basins by *Vitreisporites pustulosus*. Cheirolepidiaceae (*Classopollis* spp) and Cycadales (with *Cycadopites* and *Eucommiidites*) are recorded only in the Icó Basin. Ephedraceae records are found in Cumuruxatiba, Camamu, Potiguar, and Barreirinhas basins. The Gnetaceae, registered at many basins by the genus *Sergipea*, are also widely diversified (*Steevesipollenites*, *Sergipea* spp., *Gnetaceaepollenites*, *Elaterosporites* spp). There is a single record of Podocarpaceae, restricted to the Icó Basin (*Zonalapollenites dampieri*).

The Angiospermae must have appeared in regions where the climate would have been more stable and probably wetter during the Early Cretaceous. Some groups, however, have been adapted to drier and/or saltier conditions, with a preference for lowland, fluvial–deltaic environments (Doyle et al., 1982). The Angiospermae family Winteraceae was registered only for the Sergipe-Alagoas, Ceará, and Tucano basins, with the genus *Afropollis*.

Although the records of Pteridophyta at this interval are restricted to a single paper for the Sergipe-Alagoas (Regali and Silva Santos, 1999) and Icó (Lima, 1990) basins, their representation is exceptional in the latter, with seven families, while in Sergipe-Alagoas only two were recorded (Anemiaceae and Schizaeaceae). The latter family also has records in Cumuruxatiba, Potiguar, and Ceará basins.

Plenty of spores, particularly in the Icó Basin, are an indication of hot and humid climate (Lima, 1990), a fact also corroborated by the Lycopodiophyta records in this basin. The Pteridophyta are exceptionally well-represented in this interval at the Icó Basin, with 35 species (12 of them with indefinite affinity). The main representatives of this group are the Schizaeaceae (*Klukisporites* cf. *foveolatus* = *Foveotriletes* sp., *Reticulatisporites arcuatus*, *Appendicisporites* cf. *erdtmanii*, *A. matesovae*, *A. potomacensis*, *A. sellingii*, *Trilobosporites canadenses*, *T.* cf. *bernissartensis* and *Pilosisporites crassiangulatus*), but only the genus *Foveotriletes* was described for Cumuruxatiba, Sergipe-Alagoas, Potiguar, and Ceará basins (Regali et al., 1974, 1975). The Anemiaceae is the second most abundant family in the Icó Basin (six species of a single genus, *Cicatricosisporites*) and is present in the Sergipe-Alagoas Basin, with the same genus. Other recorded fern genera for the Icó Basin are *Cyathidites* (Cyatheaceae), *Concavisporites* and *Concavissimisporites* (Dicksoniaceae), *Marattisporites* (= *Punctatosporites;* Marattiaceae), *Verrucosisporites* (Osmundaceae) and *Granulatisporites* (Salviniacea).

The lycopods were recorded only for the Icó Basin, with the families Lycopodiaceae and Selaginellaceae (Lima, 1990). There were no records of bryophytes for this interval. The absence of lycopods in Sergipe-Alagoas, together with the scarcity of ferns, suggests that the climatic conditions would be a little more arid and dry at this basin during this interval.

4.1.1. Climate, ecology and paleogeography

Based on the ecological particularities of each of the families/orders registered for the study basins, it is possible to infer their geographic distribution and association with each of the depositional systems (alluvial–fluvial–lacustrine) interpreted for the related stratigraphic units.

For this interval, climatic and ecological interpretations were divided into three sets: east-margin basins, represented by Sergipe-Alagoas; interior basins, represented by the Icó Basin, and the equatorial-margin basins records assembled into a single set, representative of regional conditions prevailing at the considered time (Fig. 4).

At the Icó Basin, Podocarpaceae and Cupressaceae would occupy the higher altitudes (the Cupressaceae in transitional areas and smaller altitudes), represented by mountains and piedmont alluvial deposits, under cold to hot, dry climate (Fig. 4). Only the Cupressaceae were recorded for the Sergipe-Alagoas and equatorial-margin basins, occurring associated with the Coniferae *incertae sedis Complicatisaccus cearensis* and possibly with Caytoniaceae over the highlands.

The river plains should exhibit a higher botanical diversity. In Sergipe-Alagoas and Icó, the Cupressaceae were distributed in these plains, with *Exesipollenites* developing close to wetter areas associated with occasional Ephedraceae. In Icó, they also occur associated with Cycadales. In this basin, the humid conditions would probably be more effective, providing a wide distribution of ferns, either shrubby (as Cyatheaceae and Dicksoniaceae), or smaller specimens widely covering the soil in the more humid areas (Anemiaceae, Schizaeaceae, Marattiaceae, Osmundaceae). Within the water bodies, would occur the Salviniaceae and, on its banks, bryophytes from the Lycopodiaceae and Selaginellaceae families. The climatic conditions in Sergipe-Alagoas would be drier occurring, besides the Cupressaceae, the Caytoniaceae, Gnetaceae, and Winteraceae, an Angiospermae not recorded in Icó. In this context, Anemiaceae grew over the soil or as epiphytes in both basins. The absence of Lycopodiophyta and other Pteridophyta families (particularly Salviniaceae) in Sergipe-Alagoas would indicate the scarcity of permanent water bodies or wet areas. In the coastal plains of both basins, would abound the Araucariaceae with Cheirolepidiaceae restricted to the Icó Basin, which would imply the existence of more stressing environments, probably salty, but humid. This, in turn, would occur associated with lycopods and large ferns of the Cyatheaceae family. For the equatorial-margin basins, it is assumed that either the data are not representative of the paleovegetation, or the conditions would be very arid, a fact that may explain the low diversity of ferns, and the poor records of lycopods and bryophytes. In addition to the preferential occurrence of the Coniferae *incertae sedis* at the highlands, Cupressaceae and Gnetaceae could develop in transitional areas of medium altitude and milder climate. Interior, more arid plains, would present a vegetation cover with a predominance of Ephedraceae and Cupressaceae. In the wetter portions occur, in addition to Cupressaceae, the Caytoniaceae and Gnetaceae. The Ephedraceae would occur also associated with a few river systems, with Caytoniaceae, Schizaeaceae, and rare Winteraceae occurring in the fluvial-deltaic plains. Caytoniaceae and Gnetaceae would also be adapted to humid coastal regions, yet under the marine-evaporitic influence.

4.2. Top of the upper Aptian (P-270 zone)

The uppermost portion of upper Aptian corresponds to the range of the palynological zone defined by the presence of the pollen *Sergipea variverrucata* (Gymnospermae, Gnetaceae; P-270 zone) and absence of *Inaperturopollenites turbatus* (Angiospermae, Cupressaceae) being assigned to the upper Gargasian (upper Aptian), an interval corresponding to the upper middle Alagoas, on a local stage scale. It is a very well studied interval, while still diversely evaluated on the east-margin basins (Sergipe-Alagoas, Tucano), equatorial-margin basins (Potiguar, Ceará, Parnaíba, Barreirinhas, Ilha Nova, São Luís, Pará-Maranhão, and Bragança-Viseu) and the interior basins (Jatobá, Araripe). The Sergipe-Alagoas Basin (Regali et al., 1974, 1975; Regali, 1987a, b, c, 1989; Dino, 1996; Regali and Silva Santos, 1999; Carvalho, 2001; Lima Filho and Silva Santos, 2001*in*Tomé et al., 2006), Jatobá (Lima, 1984a, b) and Araripe (Duarte, 1989, 1993; Regali, 1989; Mohr and Eklund, 2003; Rydin et al., 2003; Kunzmann et al., 2004, 2006, 2007, 2011; Mohr and Bernardes-de-Oliveira, 2004; Dilcher et al., 2005; Bernardes-de-Oliveira et al., 2006; Batten, 2007; Fanton et al., 2007; Martill et al., 2007; Kerkhoff and Dutra, 2008; Mohr et al., 2008; Rios-Netto et al., 2012; Ricardi-Branco et al., 2013; Portela et al., 2014) are those with the most diverse record.

The climatic and ecological interpretations came mainly from records from the Sergipe-Alagoas, Araripe, and Jatobá basins; however, some inferences can be made based on records for the equatorial margin (Table 2). The paleobotanic data came from the Muribeca (Sergipe-Alagoas Basin) and Cabo (Cabo Sub-basin, the northern portion of the Sergipe-Alagoas Basin) formations, Santana Formation, Crato Member (Araripe Basin) and Marizal Formation (Jatobá Basin). These units are interpreted as originated from an alluvial–fluvial–lacustrine and transitional from marine-evaporitic to a marine depositional system (Sergipe-Alagoas and Araripe) and alluvial–fluvial–shallow lacustrine (Jatobá and Cabo). At the equatorial-margin basins, the records came from the Alagamar (Potiguar), Paracuru (Ceará) and Grajaú/Codó (Parnaíba, Barreirinhas, Ilha Nova, São Luís, Bragança-Viseu, Pará-Maranhão) formations, which make up an alluvial–fluvial–deltaic–lacustrine depositional system, with marine influence at the easternmost sections.

The floristic diversity for the different groups is relatively homogeneous for this interval. When compared to the previous one, it is remarkable the expressive representation of Angiospermae, which overcomes the Gymnospermae at the Sergipe-Alagoas and Araripe basins, but the Gymnospermae maintain their supremacy at the other studied basins. The Araripe Basin, nevertheless, has the greatest diversity for all groups.

While at the previous interval the Cupressaceae were the dominant Gymnospermae, the Gnetaceae, distributed in 14 of the 16 studied basins, now occupies this position with relative advantage by more than a dozen species. This family is represented in all these basins by *Sergipea variverrucata* (index fossil for this zone), *Sergipea naviformis*, *S. tenuiverrucata* and *S. simplex* (Sergipe-Alagoas, only the latter at the Cabo Sub-basin), *Cariria orbiculiconiformis*, *Elaterosporites* sp., *Gnetaceaepollenites barghoornii*, *G. boltenhagenii*, *Sergipea naviformis*, *Steevesipollenites binodosus*, *Elaterocolpites* sp., *Singhia reyrei*, and *Sofrepites* (Araripe), *Sergipea naviformis*, *Steevesipollenites* aff. *binodosus*, *Singhia reyrei* (Jatobá), *Gnetaceaepollenites barghoornii* and *Sergipea naviformis* (São Luís).

Though the Cheirolepidiaceae were very poorly represented at the previous interval, at this interval they occur with several genera, with a predominance of *Classopollis* and *Brachyphyllum*, although not recorded for all studied basins. They are diversely represented, though not in all basins, by *Brachyphyllum obesum* (Tucano), *Classopollis noeli*, *Brachyphyllum castilhoi*, *B. obesum*, *Lindleycladus* sp., *Frenelopsis* sp., *Circulina meyeliana*, *Tomaxellia biforme* (Araripe), *Classopollis classoides* (Cabo), *Classopolis torosus* (Jatobá), *Classopollis* spp. (São Luís; Pedrão et al., 2002; Ferreira et al., 2008), and *Classopollis* (Barreirinhas; Pedrão et al., 2002). Its wider distribution suggests the expansion of more stressful, hot and dry, arid environments at coastal areas. This expansion may be a reflection of the implementation of transitional environments, with marine-evaporitic influence, recorded in several of the studied basins, though is remarkable the absence of this family in the Sergipe-Alagoas Basin (sensu stricto), maybe due the lack of published studies.

The Cupressaceae is restricted to the eastern margin, from Sergipe-Alagoas to the Potiguar Basin and to the interior basins. Other Gymnospermae families are distinctly represented. The Araucariaceae are restricted also to the eastern margin (Sergipe-Alagoas; *Araucariacites*) and interior basins (Araripe and Jatobá), but with greater diversity in the interior basins, especially in Araripe (*Araucaria*, *Araucariacites*, *Bennettiaepollenites*, and *Araucarites*). The Caytoniaceae are distributed from Camamu to Barreirinhas with *Vitreisporites*, also including the genus *Caytopollenites* in Sergipe-Alagoas and *Sagenopteris* in Araripe. The Podocarpaceae have a wide distribution, but with greater diversity recorded in Sergipe-Alagoas (*Caliallasporites dampieri*, *C. segmentatus*, *Triangulopsis discoidalis*, and *T. minor*), suggesting more favorable conditions for their development in this area. Except for the records from São Luís (Pedrão et al., 2002; Ferreira et al., 2008) and Potiguar (Dino, 1996), the Cycadales and Ephedraceae have a distribution restricted to the so-called "central basins" (Souza-Lima, 2006), with Ephedraceae occurring also in Ceará. In Araripe and Jatobá, the Cycadales have greater diversity (*Cycadopites*, *Eucommiidites*, and *Bennettitaepollenites*). The Ephedraceae have a greater diversity also in Araripe (*Ephedra*, *Ephedripites*, *Equisetosporites*, *Galeacornea*, *Itajuba*, *Senegalosporites*, and *Sofrepites*); in other basins, only *Equisetosporites* was recorded.

By extension of the lower (P-260) and higher (P-280) occurrences, the Coniferae *incertae sedis Complicatisaccus cearensis* would possibly be recorded at this interval for the Camamu, Sergipe-Alagoas, Ceará, and Barreirinhas basins.

The Ulmanniaceae (*Alisporites*), Welwitschiaceae (*Welwitschiella, Welwitschiostrobus, Priscowelwitschia, Cratonia*, and *Drewria*) and Williamsoniaceae (*Williamsonia*) have records restricted to the Araripe Basin.

At this interval, the Angiospermae presents a diversity acme, suggesting that the environments and the prevailing climatic conditions were favorable for the development and expansion of this group, at least on the eastern margin, up to the Potiguar Basin. At the equatorial margin, there is a predominance of Gymnospermae. They are well, though differently represented in Sergipe-Alagoas and Araripe basins. Only sporadic records occur in Tucano, Jatobá, Potiguar, Ceará and São Luís basins. The families Liliaceae (with *Psiladicolpites laevis* – Sergipe-Alagoas, Potiguar, Ceará, and Barreirinhas basins), Euphorbiaceae (mainly *Stellatopollis* spp. – Sergipe-Alagoas, Jatobá, Araripe, and São Luís basins), Gunneraceae (various genera – Sergipe-Alagoas, Araripe, Potiguar, and São Luís basins) and Winteraceae (*Afropollis* spp.) are those with the largest geographical distribution. The Winteraceae, except for the Magnoliaceae *Trifossapollenites*, recorded for the Cabo Sub-basin (Sergipe-Alagoas Basin), was the unique Angiospermae family recorded in the previous interval, expanded to other basins in this interval (e.g., Araripe and São Luís).

Some forms of Fabaceae, represented by the genus *Striatopollis*, *Foveotricolpites*, and *Striopollenites*, occur at the Araripe and Potiguar basins. The Acanthaceae have records only in the Sergipe-Alagoas and Potiguar basins with the genus *Cornetipollis*. The Aquifoliaceae are present only in the Sergipe-Alagoas Basin with the genus *Gemmatricolpites* (Regali and Silva Santos, 1999). The Bignoniaceae were recorded only in the Potiguar Basin, with *Albertipollenites* (Dino, 1996).

The Arecaceae (with *Retimonocolpites*), Cabombaceae (with *Pluricarpellatia*), Calycanthaceae (with *Araripia*), Circaeasteraceae (with *Klitzschophyllites*), Eupomatiaceae (with *Endressinia*), Ranunculaceae (with *Trifurcatia*), and Trimeniaceae (with *Cretacaeisporites*) were recorded only in the Araripe Basin.

Some families were recorded only in Sergipe-Alagoas and Araripe basins: Chloranthaceae (Sergipe-Alagoas: *Asteropollis*, *Clavatipollenites*; Araripe: *Clavatipollenites*), Cyperaceae (Sergipe-Alagoas, Araripe: *Penetetrapites*), and Salicaceae (Sergipe-Alagoas, Araripe: *Rousea*).

The Magnoliaceae were recorded only for the Jatobá Basin (*Confertisulcites*) and Cabo Sub-basin (Sergipe-Alagoas; *Trifossapollenites*).

The diversity of ferns in the Araripe Basin is exceptional at this interval, with 12 recorded families, followed by Jatobá (6) and Sergipe-Alagoas (4) basins. At the equatorial margin, only Bragança-Viseu Basin exhibits records of this group, restricted to the Anemiaceae, Marsileaceae, and Schizaeaceae (Regali, 1986; Pedrão et al., 2002).

The great diversity of ferns, lycopods, and bryophytes at this interval, particularly in the Araripe Basin, is indicative of favorable climatic conditions for the development of these groups, i.e., hot and humid climate. A smaller diversity in family terms was found in Jatobá and Sergipe-Alagoas basins. The records for the equatorial margin shows they were practically absent (except for Bragança-Viseu), indicating that the region probably would be drier, with low humidity.

The main fern representatives are the Schizaeaceae (much diversified, with *Appendicisporites* and *Klukisporites* in Jatobá, *Appendicisporites*, *Klukisporites*, *Ruffordia*, and *Trilobosporites* in Araripe; *Klukisporites*, *Pelletieria*, *Pilosisporites*, *Reticulosporites*, and *Schizea* in Sergipe-Alagoas; *Chomotriletes* in Bragança-Viseu) and the Anemiaceae (though only with *Cicatricosisporites* in Jatobá, Araripe, Sergipe-Alagoas, and Bragança-Viseu).

The Equisetaceae are represented by two genera, *Granulatasporites* in Jatobá and *Equisetum* in Araripe and Tucano Sul. The Marsileaceae are represented by *Collarisporites* and *Crybelosporites* in Araripe and Sergipe-Alagoas, and by *Crybelosporites* in Bragança-Viseu.

Cyatheaceae were recorded in Jatobá (*Cyathidites*) and Araripe (*Concavissimisporites*, *Cyathidites*, and *Leiotriletes* sp. = *Deltoidospora*).

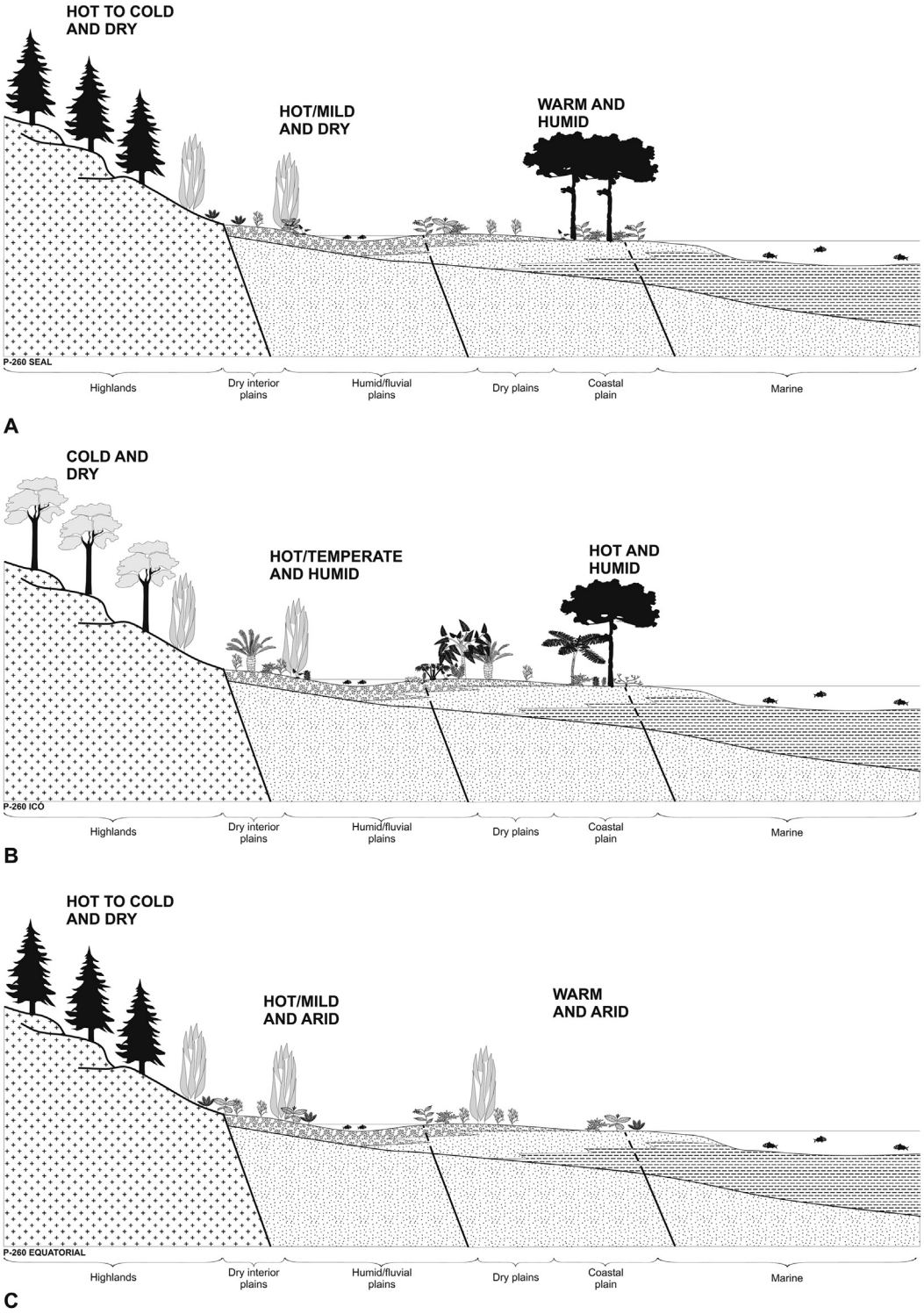

Fig. 4. Schematic transversal paleophytogeographic profiles representing the main vegetation coverage that existed during the mid portion of the late Aptian, corresponding to the interval of the palynological zone P-260. (A) East-margin basins; (B) Interior basins; (C) Equatorial-margin basins.

Osmundaceae were also recorded in Jatobá (*Todisporites*) and Araripe (*Baculatisporites*, *Verrucosisporites*). Dicksoniaceae (*Concavissimisporites*), Dipteridaceae (*Converrucosisporites*), Matoniaceae (*Boseisporites*, *Matonisporites*), Pteridaceae (*Distaltriangulisporites*) and Salviniacea (*Granulatisporites*) have records restricted to Araripe; Gleicheniaceae were recorded for Sergipe-Alagoas (*Gleicheniidites*) and Araripe (*Dictyophyllidites*) basins and Grammitidaceae only in Jatobá (*Gemmatriletes*).

Lycopodiophyta records are restricted to the Sergipe-Alagoas, Jatobá and Araripe basins, being represented by the Lycopodiaceae and Selaginellaceae families, as well as the Isoetaceae, restricted to the Araripe Basin. The presence oh these families in these basins suggests the existence of milder climatic conditions and greater humidity than those possibly existed during the same time in the equatorial margin.

The family Lycopodiaceae presents the highest diversity in the Araripe basin, with the genera *Camarozonisporites*, *Hamulatisporites*, *Leptolepidites*, and *Retitriletes*, while in Sergipe-Alagoas and Jatobá only records of *Leptolepidites* are known. The family Selaginellaceae is represented by different genera in Araripe (*Ceratosporites*, *Densoisporites*), Sergipe-Alagoas (*Densoisporites*) and Jatobá (*Echinatisporis*) basins. The Isoetaceae are represented only in Araripe by the genera *Paxillitriletes* and *Isoetites*.

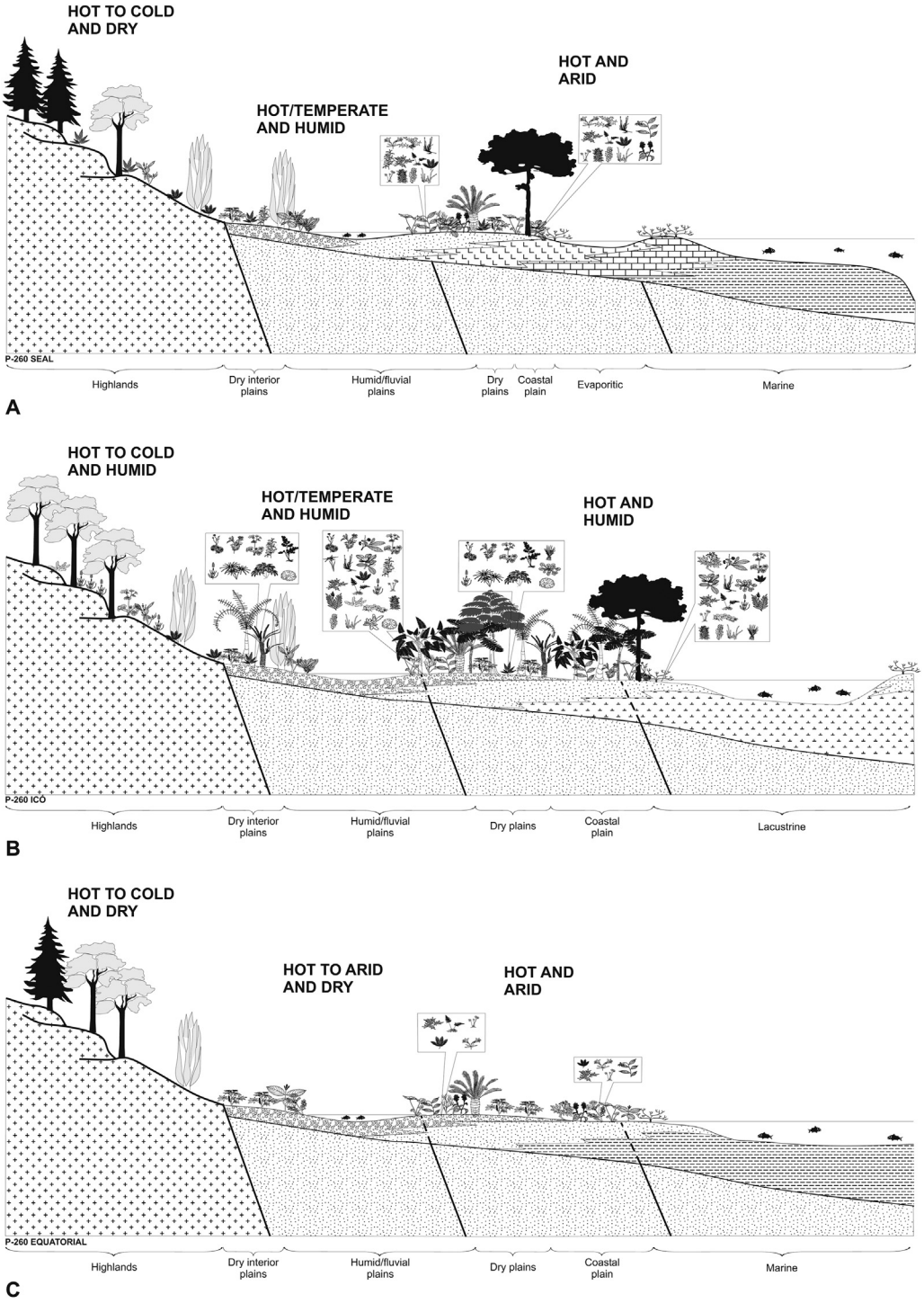

Fig. 5. Schematic transversal paleophytogeographic profiles representing the main vegetation coverage that existed during the final portion of the late Aptian, corresponding to the interval of the palynological zone P-270. (A) East-margin basins; (B) Interior basins; (C) Equatorial-margin basins.

Bryophytes were recorded only in Sergipe-Alagoas (Anthocerotaceae; *Cingulatisporites*) and Araripe basins (Anthocerotaceae, *Cingulatisporites*; Sphagnaceae, *Antulsporites* and Ricciaceae, *Rouseisporites*).

4.2.1. Climate, ecology and paleogeography

The climatic and ecological interpretations based on paleobotanical records were grouped into three large sets: the first covers the context of the east-margin basins, whose best records occur in Sergipe-Alagoas; the second encompasses the interior basins, with better records in Jatobá and Araripe, while the third represents the equatorial basins, covering the records between the Potiguar and Bragança-Viseu basins.

The higher areas of the East Brazilian marginal basins were probably occupied by Podocarpaceae, Chloranthaceae, and Gleicheniaceae, as well as by the Coniferae *incertae sedis Complicatisaccus cearensis*, with Cupressaceae and Caytoniaceae in the transitional areas (Fig. 5A). In the interior basins, the botanical diversity would have been greater, where representatives of Podocarpaceae, Cupressaceae, Caytoniaceae, Ranunculaceae, Chloranthaceae, and Equisetaceae grew up in the highlands, with a localized occurrence of Grammitidaceae (Fig. 5B). At the equatorial-margin basins, the main component of the highlands would be the

Podocarpaceae, possibly with the occurrence of the Coniferae *incertae sedis Complicatiscus cearensis* and Cupressaceae (Fig. 5C). This distribution probably reflects the climatic variations at that time, with wetter conditions in the interior basins, a little lower humidity in the area now occupied by the east-margin basins, and a more arid and hot climate at the current equatorial margin.

The inner plains, which were implanted in a mainly alluvial sedimentary context, would also present significant differences in vegetation cover. While in the eastern margin basins Euphorbiaceae, Gleicheniaceae, and Salicaceae would occur; in the interior basins, the diversity would be greater, with Salicaceae, Williamsoniaceae, Euphorbiaceae, Arecaceae, Cabombaceae, Calycanthaceae, Ranunculaceae, Equisetaceae, Matoniaceae, Dipteridaceae, Gleicheniaceae, Pteridaceae, and Ricciaceae. At the equatorial margin, the few existing vegetation at the same geological context would be represented essentially by Euphorbiaceae, nevertheless rare. In the interior basins, there may be more typical representatives of stressful environments, which would probably grow in dry river beds, such as Ulmanniaceae, Williamsoniaceae, Welwitschiaceae, Circaeasteraceae, Pteridaceae, Isoetaceae, and Ricciaceae.

In the humid interior plains and along the fluvial–deltaic plains, where there would probably be flooded freshwater environments, diversity would be greater. At the east-margin basins Gnetaceae, Cupressaceae, Caytoniaceae, Cycadales, Ephedraceae, Liliaceae, Winteraceae, Gunneraceae, Acanthaceae, Aquifoliaceae, Chloranthaceae, Cyperaceae, Salicaceae, Magnoliaceae, Schizaeaceae, Anemiaceae, Marsileaceae, Lycopodiaceae, Selaginellaceae, and Anthocerotaceae would occur. At the interior basins Cupressaceae, Caytoniaceae, Cycadales, Ephedraceae, Winteraceae, Gunneraceae, Cabombaceae, Calycanthaceae, Eupomatiaceae, Ranunculaceae, Trimeniaceae, Chloranthaceae, Cyperaceae, Salicaceae, Schizaeaceae, rare Magnoliaceae, Anemiaceae, Equisetaceae, Marsileaceae, Cyatheaceae, Osmundaceae, Dicksoniaceae, Salviniaceae, rare Grammitidaceae, Lycopodiaceae, Selaginellaceae, Anthocerotaceae, Sphagnaceae, and Ricciaceae would grow. At the equatorial-margin basins, the biodiversity is comparatively always smaller in all environments. Thus, even in the humid plains, the vegetal cover would be poor, represented by Gnetaceae, Caytoniaceae, Liliaceae, Winteraceae, and Gunneraceae, with rare Cycadales, Ephedraceae, Acanthaceae, Bignoniaceae, Anemiaceae, Schizaeaceae, and Marsileaceae.

In the humid lowlands along the coast, both at the eastern marginal and interior basins, probably ombrophilous forests would be developed. At the eastern margin basins, its main representatives would be the Araucariaceae, Caytoniaceae, Liliaceae, Winteraceae, Gunneraceae, Acanthaceae, Aquifoliaceae, Cyperaceae, Magnoliaceae, Schizaeaceae, Anemiaceae, Marsileaceae, Lycopodiaceae, Selaginellaceae, and Anthocerotaceae. In the interior basins would grow Araucariaceae, Caytoniaceae, Winteraceae, Gunneraceae, Fabacea, Arecaceae, Cabombaceae, Calycanthaceae, Circaeasteraceae, Eupomatiaceae, Ranunculaceae, Cyperaceae, rare Magnoliaceae, Schizaeaceae, Anemiaceae, Equisetaceae, Marsileaceae, Cyatheaceae, Osmundaceae, Dicksoniaceae, Salviniaceae, Lycopodiaceae, Selaginellaceae, Isoetaceae, and Anthocerotaceae. At the equatorial margin, would occur a less diversified vegetation composed by Gnetaceae, Caytoniaceae, Liliaceae, Winteraceae, Gunneraceae and rare Fabacea, Acanthaceae, Bignoniaceae, Schizaeaceae, and Marsileaceae. The absence of lycopods and bryophytes probably indicate dryer climate conditions.

At that time, in all the studied basins, to a greater or lesser extent, environments of restricted marine water circulation were being implanted, subject to intense evaporation. At least in the east and equatorial coasts, they would be associated with the marine ingressions that preceded the implantation of the South Atlantic Ocean. In these more stressful coastal environments, the vegetal cover would be much reduced, being represented in both margins by the Cheirolepidiaceae, whereas in the interior basins would occur, in addition to Cheirolepidiaceae, Cabombaceae, Circaeasteraceae, and Isoetaceae.

4.3. Uppermost upper Aptian (P-280 zone)

The uppermost part of the upper Aptian corresponds to the zone defined by the presence of the pollen *Complicatisaccus cearensis* (Coniferae *incertae sedis*, zone P-280) and absence of *Sergipea varriverrucata* (Gymnospermae, Gnetaceae). It is attributable to the uppermost portion of the Gargasian and to the Clansayesian (upper Aptian) and possibly to the lower portion of the lower Albian, corresponding locally to the upper Alagoas stage. It is an interval with few data for the East Brazilian marginal basins, practically restricted to Sergipe-Alagoas (Regali et al., 1974, 1975; Duarte, 1989; Regali, 1989; Dino, 1996; Regali and Silva Santos, 1999; Carvalho, 2001; Lima Filho and Silva Santos, 2001 in Tomé et al., 2006), and diversely studied in the equatorial basins (Potiguar, Ceará, Barreirinhas, São Luís, Pará-Maranhão, and Bragança-Viseu; Regali and Gonzaga, 1985; Regali et al., 1985; Regali, 1989; Dino, 1996; Regali and Silva Santos, 1999; Pedrão et al., 2002; Ferreira et al., 2008).

The climatic and ecological interpretations came mainly from the records from the Sergipe-Alagoas Basin, to the eastern margin, and from the Potiguar, Ceará, Barreirinhas, São Luís, and Bragança-Viseu basins, to the equatorial margin (Table 3). The existing paleobotanical data were obtained from the Muribeca and Riachuelo formations (Sergipe-Alagoas Basin) and Cabo (Cabo Sub-basin), Alagamar Formation (Potiguar Basin); Paracuru Formation (Ceará Basin), Arpoador Formation (Canárias Group, Barreirinhas Basin) and Itapecuru Formation (São Luís Basin). For the Muribeca Formation it is interpreted a transitional alluvial to marine evaporitic/marine depositional system, for the Riachuelo Formation an alluvial–fluvial–deltaic–marine depositional system, with development of a wide carbonate platform, and for the other lithostratigraphic units of the equatorial basins, an alluvial–fluvial–deltaic lacustrine to transitional evaporitic marine depositional system is assumed, the latter in particular to the more eastern basins.

It is an interval with a much-diversified record, with several families represented in the five floristic groups here considered. The Gymnospermae are very well represented in Sergipe-Alagoas and on the equatorial margin, particularly in Ceará, Barreirinhas, São Luís, and Bragança-Viseu basins. In these basins, there is no predominant family. Representatives of the families Cheirolepidiaceae, very common in the previous interval, are absent, being very reduced the presence of Cycadales, with records only in the Potiguar Basin. Also missing are representatives of the Ulmanniaceae, Welwitschiaceae, and Williamsoniaceae, previously found only in the Araripe Basin. The Coniferae incertae sedis *C. cearensis*, which characterizes this interval, together with the Podocarpaceae, are the Gymnospermae with the largest distribution.

Unfortunately, we do not have any environmental or climatic inferences for the dominant Gymnospermae in this interval, *C. cearensis*. However, it is remarkable the absence of Cheirolepidiaceae, thus assuming that stressful environmental conditions would not be common.

The Podocarpaceae are well represented in all basins with records of the genera *Caliallasporites*, *Parvisaccites*, and *Rugubivesiculites*.

Complicatiscus cearensis and the Podocarpaceae are followed, in geographic distribution, by the Caytoniaceae and Cupressaceae. The Caytoniaceae are represented in Sergipe-Alagoas and Barreirinhas by the genera *Vitreisporites* and *Caytonipollenites*, in Bragança-Viseu, São Luís, and Ceará by the genus *Vitreisporites*, and with *Caytonipollenites* in the Potiguar Basin. The Cupressaceae have records for almost all the study basins, except for Tucano, Camamu, and Pará-Maranhão basins. The genera *Exesipollenites* and *Inaperturopollenites* were recorded in all other basins, except for the Potiguar Basin, from where only the genus *Uesuguipollenites* is known.

The Araucariaceae are represented by the genus *Araucariacites* in Sergipe-Alagoas, Ceará, Barreirinhas, São Luís, and Bragança-Viseu.

The family Ephedraceae is present only in Sergipe-Alagoas (with *Equisetosporites*), Ceará (*Equisetosporites* and *Pentapsis*), Barrerinhas (*Elateroplicites* and *Pentapsis*), and São Luís (all previous). The family Gnetaceae is present in Sergipe-Alagoas, Ceará, Barrerinhas, São Luís, and Bragança-Viseu basins with several genera, among them *Sergipea*, *Gnetaceaepollenites*, *Steevesipollenites*, and *Elateropollenites*.

The greatest diversity of Angiospermae was recorded for the Sergipe-Alagoas Basin, but significant records also occur in the equatorial basins.

The Angiospermae family Winteraceae exhibits the widest distribution but was recorded only by the genus *Afropollis* in Sergipe-Alagoas, Tucano, Araripe, Potiguar, Ceará, and Barreirinhas. The Trimeniaceae follow the Winteraceae in representativeness with records restricted to Sergipe-Alagoas, Ceará, Barreirinhas, São Luís, and Bragança-Viseu, exclusively represented by the genus *Cretacaeiporites*.

The Fabaceae were recorded in the Sergipe-Alagoas, Potiguar, Ceará and Barreirinhas basins by the genera *Striopollenites* and *Striatopollis* (considered synonymous).

The Gunneraceae were recorded only in Sergipe-Alagoas, Ceará, and Barreirinhas with the genera *Brenneripollis*, *Retitricolpites*, and *Tricolpites*, with *Dejaxpollenites* recorded for the Sergipe-Alagoas and Potiguar basins.

The Liliaceae were recorded for the Sergipe-Alagoas, Potiguar, Ceará, and Barreirinhas basins with the genus *Psiladicolpites*; *Liliacidites* was also found in Sergipe-Alagoas. The Euphorbiaceae were recorded for the Barreirinhas, São Luís, and Sergipe-Alagoas basins with the genus *Stellatopollis*; *Psilatricolpites* occur also in Sergipe-Alagoas. The family Magnoliaceae was recorded only by the genus *Trifossapollenites* for the Sergipe-Alagoas (including the Cabo Sub-basin), Barreirinhas, and Ceará basins. The Acanthaceae were recorded only in Sergipe-Alagoas and Potiguar basins by a single genus, *Cornetipollis*. The Chloranthaceae

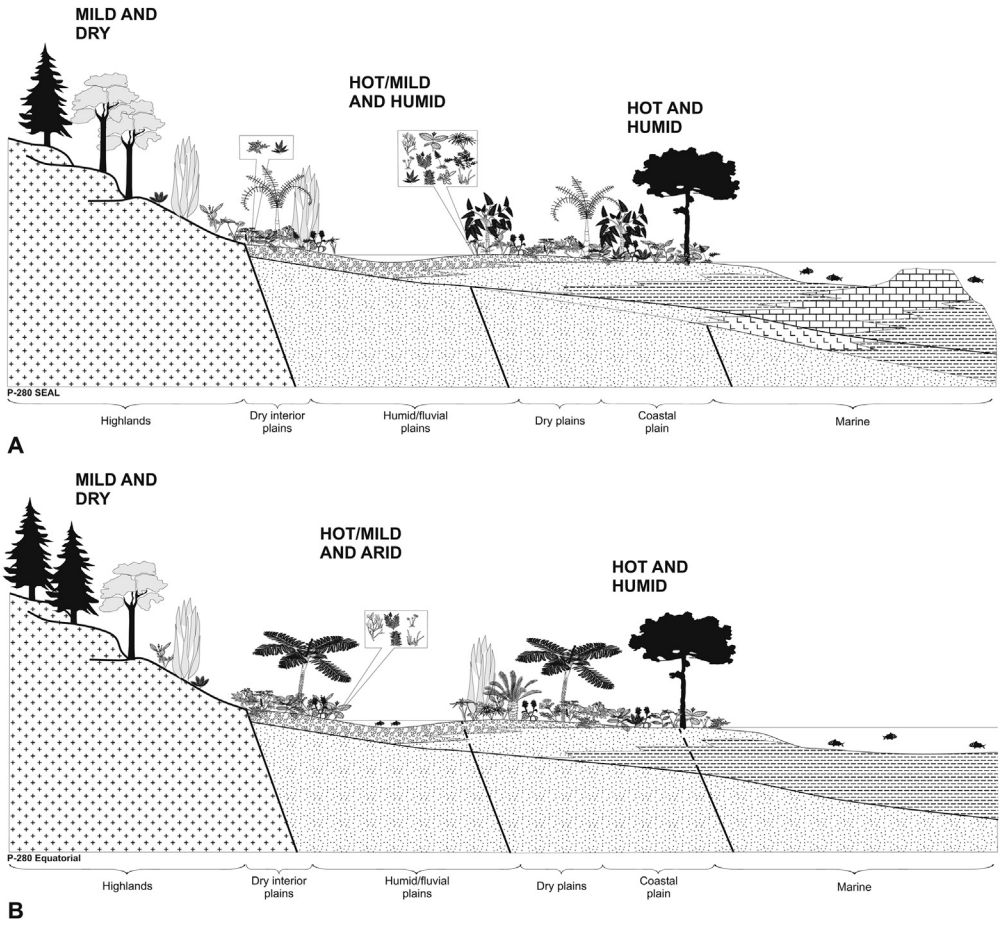

Fig. 6. Schematic transversal paleophytogeographic profiles representing the main vegetation coverage that existed during the final of the late Aptian, corresponding to the interval of the palynological zone P-280. (A) East-margin basins; (B) Equatorial-margin basins.

were represented in Sergipe-Alagoas, Ceará, and Barreirinhas basins by the genus *Clavatipollenites*. The family Arecaceae (with *Retimonocolpites*) has records only for the Sergipe-Alagoas Basin. The Bignoniaceae, with the genus *Albertipollenites*, have records only for the Potiguar Basin.

The greater Pteridophyta diversity for the interval is recorded for the Sergipe-Alagoas Basin (eight families), with less diversified occurrences for Ceará and Barreirinhas basins (four and five families, respectively). The Matoniaceae (with *Matonisporites*) exhibit the wider distribution, occurring in Sergipe-Alagoas, Ceará, Barreirinhas, São Luís, and Bragança-Viseu basins. They are followed by the Marsileaceae, occurring in Sergipe-Alagoas, Ceará, Barreirinhas, and Bragança-Viseu basins with the genera *Crybelosporites* and *Paludites*, both sometimes considered synonymous (Antonioli, 1998), and *Collarisporites* (exclusively in Sergipe-Alagoas).

The Osmundaceae (with the genus *Verrucosisporites*) were registered only in Sergipe-Alagoas, Ceará, and Barreirinhas. The Schizaeaceae have records for the same basins, with several genera (*Schizea*, *Trilobosporites*, *Reticulosporis*, *Pelletieria*, *Pilosisporites*) in Sergipe-Alagoas and only the first one in the others.

The records of Anemiaceae (*Cicatricosisporites*), Dicksoniaceae (*Murospora*), Gleicheniaceae (*Gleicheniidites*), and Tedeleaceae (*Raistrickia*) are exclusive to the Sergipe-Alagoas Basin. The family Cyatheaceae has records only for Barrerinhas Basin, with the genus *Cardioangulina*.

Lycopods are represented only by Lycopodiaceae (*Retitriletes/Leptolepidites*) in Sergipe-Alagoas, Ceará, Barreirinhas, and São Luís, while bryophytes are represented by Anthocerotaceae (Sergipe-Alagoas, Potiguar, Ceará, and Barreirinhas, with *Cingulatisporites*) and Sphagnaceae (with *Antulsporites*), restricted to the Sergipe-Alagoas Basin.

4.3.1. Climate, ecology and paleogeography

The phytogeographic distribution of each family can be inferred based on their ecological characteristics. Although three distinct lithostratigraphic units are reported for the Sergipe-Alagoas basin during this interval (Muribeca, Riachuelo, and Cabo formations), the paleoflora does not show significant changes between them. The absence of Cheirolepidiaceae, not only in the eastern basins but also in the equatorial margin, suggests the lack of significant extensions of stressful environments, particularly coastal environments dominated by evaporitic marine sedimentation.

For this interval, the phytogeographic scenario is very similar for the eastern and equatorial-margin basins, except for small peculiarities. In the east-margin basins, here exemplified by the Sergipe-Alagoas Basin (Fig. 6A), the highlands and its associated alluvial areas, at milder climate, would be preferentially occupied by Podocarpaceae, Caytoniaceae, Cupressaceae, Coniferae *incertae sedis* (*Complicatisacus cearensis*), and Chloranthaceae, with the development of Gunneraceae towards lowland transition areas. In the more arid and hotter areas of the lowlands, Angiospermae from the Fabaceae, Euphorbiaceae, Magnoliaceae, Acanthaceae, and Arecaceae families, and a greater diversity of ferns, represented by Schizaeaceae, Anemiaceae, Dicksoniaceae, and Gleicheniaceae would be developed. In the vicinity of the watercourses, ponds and flooded areas, under milder climatic conditions, there would be Gymnospermae of the family Cupressaceae, besides Angiospermae of the families Trimeniaceae, Acanthaceae, Chloranthaceae, and Liliaceae. In these environments, the ferns exhibit great diversity represented by the families Matoniaceae, Marsileaceae, Osmundaceae, Anemiaceae, Dicksoniaceae, and Tedeleaceae, as well as lycopods (Lycopodiaceae) and bryophytes (Anthocerotaceae and Sphagnaceae). In the fluvial-deltaic plains, Ephedraceae and Gnetaceae (*Sergipea*, *Gnetaceaepollenites*, *Steevesipollenites*) would be found, being less frequent the presence of Angiospermae, with the exception of Liliaceae. On the other hand, ferns would also be abundant, with representatives of Marsileaceae, Osmundaceae, Anemiaceae, Dicksoniaceae, Tedeleaceae, and Gleicheniaceae, as well as lycopods and bryophytes (Anthocerotaceae and Sphagnaceae). In the coastal region, under the direct influence of the sea and in warmer climatic conditions, would occur Araucariaceae, Gnetaceae (*Elateropollenites*), Winteraceae (*Afropollis*), Gunneraceae, Acanthaceae, Caytoniaceae, and Pteridophyta of the families Marsileaceae, Schizaeaceae, and Anemiaceae.

In the equatorial margin (Fig. 6B), at the highlands and its associated alluvial areas, under mild climate, would be found representatives of Podocarpaceae, Cupressaceae, Caytoniaceae, Coniferae *incertae sedis* (*C. cearensis*), and Chloranthaceae. Gunneraceae would occur in transition areas toward the lowlands. In the lowlands, under warmer and arid conditions, there would be predominantly Angiospermae of the families Fabaceae, Euphorbiaceae, Magnoliaceae, Acanthaceae, and Bignoniaceae (the latter only registered for the Potiguar Basin), as well as ferns of the families Schizaeaceae (Ceará and Barreirinhas) and Cyatheaceae (Barreirinhas). Areas close to water bodies such as rivers, swamps, and lakes, and in the fluvial–deltaic plains, would be occupied by Gymnospermae of the families Cupressaceae, Ephedraceae, and Gnetaceae (*Sergipea*, *Gnetaceaepollenites*, *Steevesipollenites*), rare Cycadales, Angiospermae (Trimeniaceae, Chloranthaceae, and Acanthaceae), and a diverse population of ferns (Matoniaceae, Marsileaceae, and Osmundaceae), together with lycopods (Lycopodiaceae) and bryophytes (Anthocerotaceae). The coastal region, locally under marine influence, but without the development of stressful ecosystems, would be colonized predominantly by Araucariaceae, Gnetaceae (*Elateropollenites*), Winteraceae (*Afropollis*), Gunneraceae, Acanthaceae, Caytoniaceae, and by ferns (Marsileaceae and Schizaeaceae), under warmer conditions.

4.4. Lower Albian (P-320 zone)

The interval here referred to as "lower Albian" corresponds to the zone defined by the presence of *Elateropollenites jardinei* (Gymnospermae, Gnetaceae?, Zone P-320) and absence of *C. cearensis* (Gymnospermae, Coniferae *incertae sedis*). It is a very little studied interval at the Northeast Brazilian eastern margin basins, except for Sergipe-Alagoas (Regali et al., 1974, 1975; Regali, 1987b; Regali and Silva Santos, 1999; Lima Filho and Silva-Santos, 2001 in Tomé et al., 2006; Dutra et al., 2002), Cumuruxatiba and Camamu (Regali et al., 1974, 1975), and relatively well known for the equatorial-margin basins, especially Potiguar (Regali et al., 1974, 1975; Beurlen, 1982; Regali and Gonzaga, 1985; Dino, 1996), Ceará (Regali and Silva Santos, 1999; Pedrão et al., 2002), Parnaíba (Pedrão et al., 2002; Ferreira et al., 2010), Barreirinhas (Herngreen, 1973; Regali et al., 1974, 1975, 1985; Beurlen, 1982; Regali, 1986; Regali and Silva Santos, 1999; Pedrão et al., 2002) and São Luís (Pedrão et al., 2002; Ferreira et al., 2008).

The published paleobotanical data came from the Riachuelo (Sergipe-Alagoas Basin), Açu (Potiguar Basin), Ubarana (Ceará Basin), Grajaú/Codó (Parnaíba Basin) and Arpoador and Tutóia (Canárias Group, Barreirinhas Basin) formations. For the Riachuelo Formation, it is interpreted an alluvial–fluvial–deltaic–marine depositional system, with the development of a wide carbonatic platform, and for the other units of the equatorial basins, an alluvial–fluvial–deltaic to lacustrine-transitional to a marine depositional system, particularly in the eastern basins (Ceará and Potiguar).

For this interval, the basins located in the equatorial margin (mainly Potiguar, Ceará, Parnaíba, and Barreirinhas basins) are those that present the greatest floristic diversities (Table 4). The Parnaíba Basin exhibits the greatest diversity with 16 families. From the eastern margin basins, only Sergipe-Alagoas contains significant records, with 10 families. Both the Gymnospermae and Angiospermae are equally represented. The records of Pteridophyta and Lycopodiophyta are very sparse, whereas no record of Bryophyta was found for this interval.

The Gnetaceae, Caytoniaceae, and Ephedraceae are the best-distributed Gymnospermae, followed by the Araucariaceae. In this group, is remarkable the low representation of Cupressaceae and Podocarpaceae, restricted to some equatorial-margin basins, while the Cycadales have sparse records for Sergipe-Alagoas and Potiguar basins.

The presence of *E. jardinei* (Gymnospermae, Gnetaceae?), one of the dominant Gymnospermae and index fossil for this interval, indicates the existence of hot climate under arid to semi-arid conditions (Herngreen and Dueñas-Jimenez, 1990; Herngreen et al., 1996; Schrank, 2001). Other Gnetaceae are represented by *Gnetaceaepollenites* (Parnaíba, São Luís, Bragança-Viseu), *Elaterosporites* (Parnaíba, Barreirinhas), *Steevesipollenites* (Parnaíba, Barreirinhas). and *Elaterocolpites* (Parnaíba), indicating similar climatic conditions.

The Ephedraceae are represented by *Ephedripsites* (Barreirinhas), *Alaticolpites* (Parnaíba, Barreirinhas), *Regalipollenites* (Barreirinhas), *Equisetosporites* (Parnaíba), and *Pentapsis* (Cumuruxatiba, Camamu, Ceará, Ilha Nova, São Luís, and Pará-Maranhão).

The Caytoniaceae are represented only by the genus *Vitreisporites* in the Camamu, Sergipe-Alagoas, Potiguar, Ceará, Parnaíba, and Barreirinhas basins. The Araucariaceae, represented exclusively by the genus *Araucariacites* in the Potiguar, Parnaíba, and Barreirinhas basins, occur in the Sergipe-Alagoas Basin with the genus *Agathoxylon*, a representative of the macroflora.

The Podocarpacea, Cupressaceae, Cheirolepidiaceae and the Cycadales have very restricted occurrence in this interval. Podocarpaceae occur only in Barreirinhas with the genus *Applanopsis* (= *Callialasporites*). The Cupressaceae present records in the Parnaíba (*Inaperturopollenites*) and Potiguar (*Uesuguipollenites*) basins. The Cycadales were recorded in Sergipe-Alagoas (with a Cycadophyta representative of the macroflora) and in the Potiguar Basin (*Bennettitaepollenites*). The Cheirolepidiaceae occur only in the Sergipe-Alagoas Basin with *Brachyphyllum* (a representative of macroflora) and in Parnaíba, with *Classopollis*.

Euphorbiaceae (*Stellatopollis*) and Winteraceae (*Afropollis*) were the Angiospermae with wider distribution, with records in several equatorial-margin basins. On the other hand, the record for the eastern margin basins is scarce, being restricted to the families Fabaceae (*Striopollenites*), Trimeniaceae (*Cretacaeisporites*), and Winteraceae (*Afropollis*), all in the Sergipe-Alagoas Basin, the first two occurrences being inferred by their extensions between the lower and upper zones. The Euphorbiaceae are represented by the genus *Stellatopollis* (Potiguar, Parnaíba, Barreirinhas, São Luís, and Bragança-Viseu). The Winteraceae are represented exclusively by the genus *Afropollis* (Potiguar, Ceará, Parnaíba, Barreirinhas, São Luís, and Bragança-Viseu). The Fabaceae are represented by *Striopollenites* (= *Striatopollis*) in Sergipe-Alagoas and Potiguar basins. The Trimeniaceae, represented by the genus *Cretacaeisporites* in the Parnaíba Basin, would also occur, by extension, in Sergipe-Alagoas, Ceará, and Barreirinhas basins.

Other groups are sparsely represented, even on the equatorial margin, particularly in the region between the Potiguar and Barreirinhas basins. Acanthaceae (with *Cornetipollis*) have records only in the Potiguar Basin. This basin also has records of Bignoniaceae (with *Albertipollenites*) and Gunneraceae (with *Dejaxpollenites*). Gunneraceae also present records for the Parnaíba Basin (with *Retitricolpites*). The Liliaceae were recorded only in the Parnaíba Basin (with *Liliacidites*).

The low record of ferns and lycopods and the absence of bryophytes suggest that the conditions would be generally drier during the early Albian. The Marsileaceae (with *Cryobosporites*) were the dominant Pteridophyta both on the eastern (recorded only in Sergipe-Alagoas) and equatorial margin (Parnaíba, Barreirinhas, São Luís, and Bragança-Viseu). Other ferns are the Anemiaceae (with *Cicatricosisporites*) and Osmundaceae (with *Biretisporites*), both recorded only in the Parnaíba Basin.

The lycopods occur in the Parnaíba Basin with Lycopodiaceae (*Leptolepidites*) and, by extension, in Sergipe-Alagoas, Ceará, and Barreirinhas with the same genus, probably of rarer occurrence in these basins.

4.4.1. Climate, ecology and paleogeography

The phytogeographic inferences for the Eastern Brazilian marginal basins are based on the records prevailing mainly for the Sergipe-Alagoas, which makes the interpretation somewhat fragile. In this basin, for the early Albian, is remarkable the inexistence of families specific to the highlands and inland plains. On the other hand, the presence of Cheirolepidiaceae, absence of bryophytes and reduced content of lycopods and ferns in both the eastern and equatorial basins is suggestive of the predominance of a warmer climate, increasing aridity and existence of more stressful environments than those would have existed during the deposition of the previous section (upper Aptian, P-280 zone). The only records for the interior basins are limited to the Gnetaceae and Winteraceae families for the Araripe Basin and are insufficient for a phytogeographic approach.

For the east-margin basins (Fig. 7A) there is a much-reduced family diversity. The absence of representatives of the Podocarpaceae, Coniferae, and Cupressaceae suggests the absence of highlands and mild to temperate climates, indicating that the previously existing highlands would already be eroded and the climate would probably be warmer. In the interior humid and fluvial-deltaic plains, there would be representatives of the Caytoniaceae, Cycadales, Winteraceae, Marsileaceae, and Lycopodiaceae, and in the latter could also occur representatives of the Fabaceae and Trimeniaceae. In the arider interior plains would occur representatives of Ephedraceae. In the coastal lowlands, with greater humidity, specimens of the families Gnetaceae, Araucariaceae, Caytoniaceae, Fabaceae, Winteraceae, Marsileaceae, and Lycopodiaceae would grow, while in the more stressful coastal environments, under marine or even evaporitic influence, there would be the representatives of Cheirolepidiaceae.

For the equatorial-margin basins (Fig. 7B), the paleobotanical diversity would be significantly greater, but smaller than the one existing for the previous interval (corresponding to the P-280 zone). The highlands would probably be sparsely vegetated, with rare specimens of Podocarpaceae, Cupressaceae, and Chloranthaceae. In the interior plains would occur representatives of Ephedraceae, Euphorbiaceae, and Arecaceae. Greater diversity would be found in more humid environments. In the interior humid plains possibly occur Caytoniaceae,

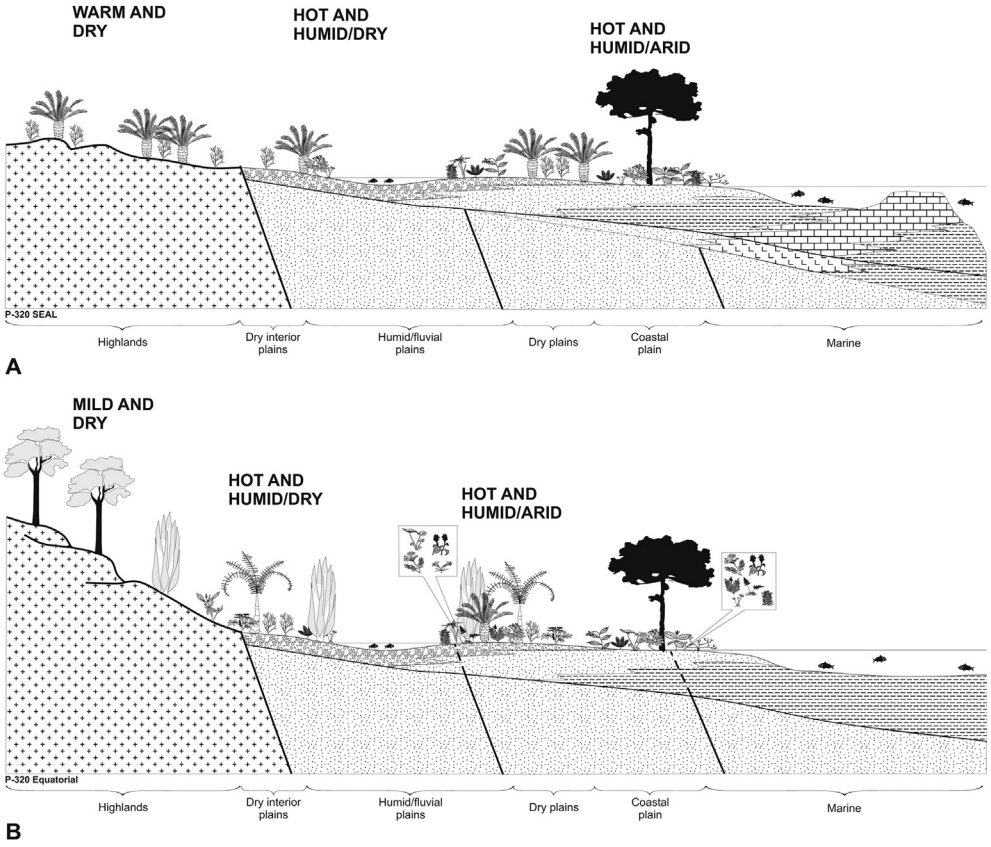

Fig. 7. Schematic transversal paleophytogeographic profiles representing the main vegetation coverage that existed during the early Albian, corresponding to the interval of the palynological zone P-320. (A) East-margin basins; (B) Equatorial-margin basins.

Marsileaceae, and Lycopodiaceae, with more dispersed occurrences of Cupressaceae, Cycadales, Anemiaceae, and Osmundaceae. In the fluvial–deltaic plains, there would be a predominance of Caytoniaceae, Marsileaceae, Fabaceae, Trimeniaceae, and Lycopodiaceae, with rare records of Gunneraceae, Acanthaceae, Bignoniaceae, Cupressaceae, Cycadales, Liliaceae, Anemiaceae, and Osmundaceae. In the coastal lowlands, representatives of Gnetaceae, Caytoniaceae, Araucariaceae, Winteraceae, Fabaceae, Marsileaceae, and Lycopodiaceae would be found, with rarer records of Gunneraceae, Acanthaceae, Bignoniaceae, Anemiaceae, and Osmundaceae. Although not very common, specimens of the Cheirolepidiaceae would grow in stressful environments, under marine-evaporitic influence.

4.5. Middle Albian (P-330 zone)

The interval here referred to as the "middle Albian" corresponds to the zone defined by the presence of *Steevesipollenites alatiformis* (Gymnospermae, Gnetaceae, P-330 zone) and absence of *Elateropollenites jardinei* (Gymnospermae, Gnetaceae). It is an interval with few records for the Northeast Brazilian eastern margin basins, except for Sergipe-Alagoas (Regali et al., 1974, 1975; Beurlen, 1982; Regali and Silva Santos, 1999), and relatively well known for the equatorial-margin basins, especially for the Potiguar (Regali et al., 1974, 1975; Beurlen, 1982; Regali and Gonzaga, 1985; Dino, 1996), Ceará (Regali, 1986), Barreirinhas (Herngreen, 1973; Regali et al., 1974, 1975; Beurlen, 1982; Regali, 1986; Dino et al., 1999; Pedrão et al., 2002), São Luís (Pedrão et al., 2002; Ferreira et al., 2008) and Bragança-Viseu (Pedrão et al., 2002) basins.

The published paleobotanical data came from the Riachuelo (Sergipe-Alagoas Basin), Açu (Potiguar Basin), Ubarana (Ceará Basin), Tutóia (Canarias Group) and Bomfim/Preguiças (Caju Group, Barreirinhas Basin), and Itapecuru (São Luís Basin) formations. An alluvial–fluvial–deltaic–marine depositional system is interpreted for the Riachuelo Formation, with the development of a wide carbonatic platform, and for the other units of the equatorial basins, an alluvial–fluvial–deltaic lacustrine to marine depositional system, locally with development of a carbonatic platform (particularly in Barreirinhas).

In this interval, the basins located in the equatorial margin, especially the Potiguar and Barreirinhas, are those that exhibit the greater floristic diversities, with about a dozen families been represented (Table 5). From the east-margin basins, only Sergipe-Alagoas contains significant records, with eight families. Gymnospermae and Angiospermae are equally represented, although the latter was best recorded for the equatorial margin. Ferns and lycopods records are very scarce, with only one family in each of these divisions. No bryophytes were recorded in this interval.

With the exception of Cheirolepidiaceae, Gnetaceae and Caytoniaceae, the other Gymnospermae families have records only for the equatorial-margin basins. Once again, the presence of a Gnetaceae (*S. alatiformis*) as the dominant Gymnospermae in this interval, present in all the studied basins, indicates the maintenance of hot arid to semi-arid climate (Herngreen and Dueñas-Jimenez, 1990; Herngreen et al., 1996; Schrank, 2001), which prevailed from at least the Mesoalbian. Other Gnetaceae are represented by *Sofrepites* (Barreirinhas), *Elaterosporites* (Sergipe-Alagoas, Potiguar, Cumuruxatiba, São Luís, Barreirinhas) and *Gnetaceaepollenites* (São Luís).

It is supposed that there would be continuity between the occurrences of *Brachyphyllum* (Cheirolepidiaceae) in the lower Albian of the Sergipe Sub-basin and those from the upper Albian of the Cabo Sub-basin, the northern part of the Sergipe-Alagoas Basin. This would suggest locally more stressful, saline conditions in hot climate under extreme evaporation. Similar conditions may have existed in the Bragança-Viseu Basin, where this family occurs with the genus *Classopollis*.

The Caytoniaceae are represented only by the genus *Vitreisporites* in the Camamu, Sergipe-Alagoas, Potiguar, Ceará, Parnaíba, and Barreirinhas basins.

The Araucariaceae are represented by the genus *Araucariacites* (Potiguar, Barreirinhas and, by extension, São Luís).

The records of Cupressaceae, Cycadales, Ephedraceae, and Podocarpaceae are very scarce. The first two are restricted to the Potiguar Basin (*Uesuguipollenites* and *Bennettitaepollenites*, respectively). The Ephedraceae have very diverse records in Barreirinhas Basin (*Senegalosporites*, *Alaticolites*, *Regalipollenites*, *Ephedripites*) and a smaller diversity in São Luís Basin (*Alaticolpites*, *Equisetosporites*). The Podocarpaceae occur only in Barreirinhas Basin with the genus *Applanopsis* (= *Callialasporites*).

The Angiospermae are very little represented at this interval, and two of the records for the eastern margin are by extension of occurrences from lower to upper zones. The records are practically restricted to the equatorial margin, where the families with the largest distribution are the Fabaceae, Euphorbiaceae, and Winteraceae.

The occurrence of Fabaceae would cover both the eastern margin (Sergipe-Alagoas) and the equatorial margin (Ceará, Barreirinhas, and Potiguar), although only in the latter the record is effective (being by extension in the others). The Fabaceae occur with the genus *Striatopollis* (= *Striopollenites*). The Euphorbiaceae are distributed in the Potiguar, São Luís, and Bragança-Viseu basins with a single genus, *Stellatopollis*. The Winteraceae were recorded for the Sergipe-Alagoas, Araripe, Potiguar, Ceará, and Barreirinhas basins with the genus *Afropollis*.

Although the Trimenaceae have records only for the Ceará Basin (with *Cretacaeisporites*), it is assumed to occur in Sergipe-Alagoas and Barreirinhas by extension of the occurrence between the lower and upper zones.

Other Angiospermae families have very localized records, essentially restricted to the Potiguar and Barreirinhas basins. The Acanthaceae are represented by the genus *Cornetipollis* in the Potiguar Basin. The Bignoniaceae occur with *Albertipollenites*, also in the Potiguar Basin, as well as the Gunneraceae *Dejaxpollenites*. The Arecaceae are represented only in Barreirinhas Basin by *Retimonocolites*.

The record of ferns and lycopods are extremely rare for this interval, while there are no records of bryophytes. This is suggestive that the conditions would be even drier during this interval than along the Eoalbian. Only the Marsileaceae family was recorded in the Barreirinhas (*Perotriletes*) and São Luís (*Crybelosporites*) basins, being considered, by extension, the occurrence of *Collarisporites* in Sergipe-Alagoas and *Crybelosporites* in Bragança-Viseu.

The Marsileaceae is the only Pteridophyta family recorded for this interval, though restricted to the Barreirinhas and São Luís basins (with *Cryobosporites*) and, by extension, to the Sergipe-Alagoas (*Callarisporites*) and Bragança-Viseu (*Crybelosporites*) basins.

As in the lower Albian, the occurrence of Lycopodiophyta in this interval is only assumed by the extension between the upper Aptian and upper Albian records for the Sergipe-Alagoas, Ceará, and Barreirinhas basins, with the genus *Leptolepidites* (Lycopodiaceae).

4.5.1. Climate, ecology and paleogeography

The inferences for the phytogeographic distribution of the east-margin basins are very restricted for this interval, consisting of the scarce registry existing mainly for the Sergipe-Alagoas Basin. On the other hand, the existing records for the equatorial margin are somewhat broader both in terms of geographic distribution as in relation to its diversity.

One remarkable aspect, however, in both areas, is the absence of records of forms whose preferential phytogeographic distribution would be linked to the existence of highlands, indicative of a milder climate, despite there are sparse occurrences of Podocarpaceae and Cupressaceae in some basins of the equatorial margin.

Although the absence of representatives of the families Podocarpaceae, Ephedraceae, Euphorbiaceae, and Arecaceae on east-margin basins suggest a warm, relatively arid climate, the conditions would be somewhat milder than those on the equatorial margin. In both regions, humidity was restricted to the proximity of watercourses and flooded areas. On the other hand, the phytogeographic distribution for the equatorial-margin basins suggests an increase of aridity from east to west, with a milder climate to the east and warmer to the west.

On the east-margin basins, the vegetation would be better suited to grow in wetlands, near watercourses or along the coast (Fig. 8A). In the humid interior plains would preferably grow representatives of the Caytoniaceae, Marsileaceae, Trimeniaceae, and rare Lycopodiaceae. In the fluvial–deltaic plains and coastal, humid lowlands, would probably occur representatives from the Gnetaceae, Caytoniaceae, Winteraceae, Trimeniaceae, Marsileaceae, and rare Lycopodiaceae, and in the latter could be found representatives of the Fabaceae. The presence of Cheirolepidiaceae in the Cabo Sub-basin is suggestive of the existence of coastal

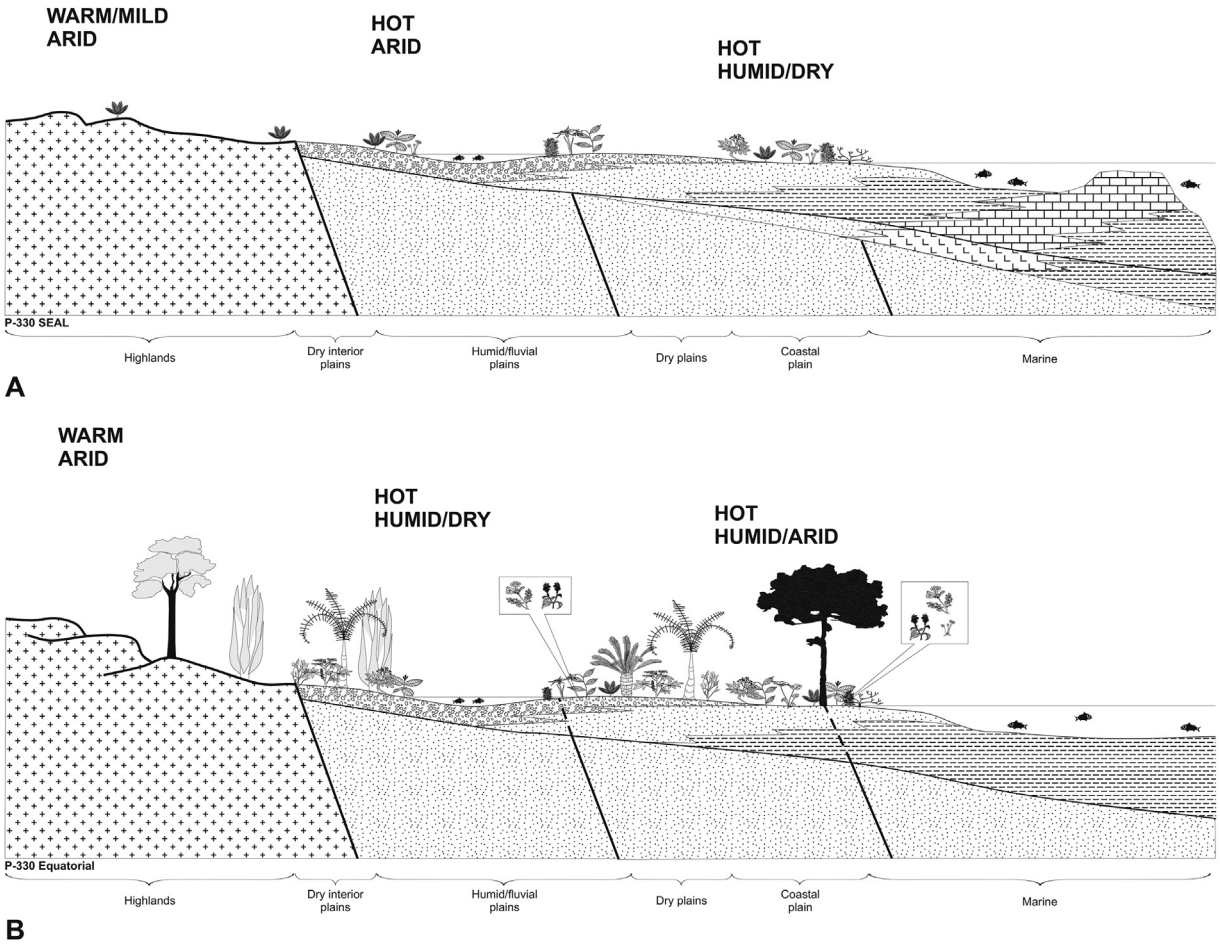

Fig. 8. Schematic transversal paleophytogeographic profiles representing the main vegetation coverage that existed during the mid-Albian, corresponding to the interval of the palynological zone P-330. (A) East-margin basins; (B) Equatorial-margin basins.

environments under a marine-evaporitic influence, at least localized. In a similar context, but in less stressful environments, it would be possible the occurrence of Gnetaceae.

The equatorial-margin basins present a rich diversity compared to the eastern margin (Fig. 8B). In their interior plains, implanted in a mainly alluvial sedimentary context, Ephedraceae and Euphorbiaceae, with rarer forms of Podocarpaceae and Arecaceae (both restricted to the Barreirinhas Basin) would grow.

In the interior humid plains, probably associated with environments flooded with freshwater, would grow representatives of the Caytoniaceae, Trimeniaceae, and Marsileaceae. In the context of the equatorial basins, possibly the easternmost basins would be more humid than those westward, a fact evidenced by the occurrence of Cupressaceae, Cycadales, Gunneraceae, and Acanthaceae in these environments. In Barreirinhas and Ceará could occur Lycopodiaceae. The fluvial–deltaic plains exhibited a rich diversity, with specimens of Caytoniaceae, Winteraceae, Marsileaceae, Fabaceae, Trimeniaceae, and Gnetaceae. Greater humidity around the Potiguar Basin would favor the development of representatives of Gunneraceae, Acanthaceae, Bignoniaceae, Cupressaceae, and Cycadales. Possible occurrences of Lycopodiaceae in Ceará and Barreirinhas would also indicate higher humidity in these basins.

In the humid lowlands along the coast, there would probably develop ombrophilous forests composed of representatives of Gnetaceae, Caytoniaceae, Araucariaceae, Winteraceae, Fabaceae, and Marsileaceae. In the surroundings of the Potiguar Basin, could have also existed Gunneraceae, Acanthaceae, and Bignoniaceae. Arecaceae would develop punctually in some regions, as in Barreirinhas.

The increase of aridity and temperature towards the west would also be demonstrated by the occurrence of Cheirolepidiaceae in Bragança-Viseu, indicating the existence of coastal environments under a marine-evaporitic influence.

4.6. Upper Albian (including zones P-355 and P-360)

The interval here called "upper Albian" corresponds to the zone defined by the presence of *Classopolis echinatus* (Gymnospermae, Cheirolepidiaceae, P-355 zone) and/or *Elaterosporites protensus* (Gymnospermae, Gnetaceae, P-360 zone) and absence of *Steevesipollenites alatiformis* (Gymnospermae, Gnetaceae).

It is a barely studied interval, with records for both the east-margin basins, such as Cumuruxatiba (Regali et al., 1974, 1975; Beurlen, 1982), Camamu (Regali and Silva Santos, 1999) and Sergipe-Alagoas (Regali et al., 1974, 1975; Beurlen, 1982; Regali, 1987b; Regali and Silva Santos, 1999; Carvalho, 2001; Lima Filho and Silva-Santos, 2001 in Tomé et al., 2006; Barbosa et al., 2008), as well as those of the equatorial margin: Potiguar (Regali et al., 1974, 1975; Beurlen, 1982; Regali and Gonzaga, 1985; Dino, 1996; Regali and Silva Santos, 1999), Ceará (Regali and Silva Santos, 1999), Barreirinhas (Herngreen, 1973; Regali et al., 1974, 1975; Beurlen, 1982; Regali et al., 1985; Dino et al., 1999; Regali and Silva Santos, 1999; Pedrão et al., 2002), Ilha Nova (Pedrão et al., 2002); São Luís (Pedrão et al., 2002; Ferreira et al., 2008) and Bragança-Viseu (Pedrão et al., 2002).

The published paleobotanical data were obtained from the Regência (Cumuruxatiba Basin), Algodões (Camamu Basin), Riachuelo (Sergipe-Alagoas Basin), Açu/Ponta do Mel/Ubarana (Potiguar Basin), Ubarana (Ceará Basin), Bomfim/Preguiças (Caju Group, Barreirinhas Basin) and Itapecuru (São Luís and Bragança-Viseu basins) formations. It is interpreted for the Regência, Algodões and Riachuelo formations, an alluvial–fluvial–deltaic–marine depositional system, with the development of a wide carbonatic platform, and for the other units of the equatorial basins, an alluvial–fluvial–deltaic lacustrine to a marine depositional system, locally with the development of a carbonatic platform (particularly in Barreirinhas).

In this interval, there is a predominance of the Gymnospermae over the Angiospermae, a group better registered for the equatorial-margin basins (Table 6). In the eastern margin, the Sergipe-Alagoas and Camamu basins present the best records. For the equatorial margin, the best records are found for the Potiguar, Ceará, and Barreirinhas basins.

An interesting feature of this interval is the wide distribution of the family Cheirolepidiaceae, which comprises the index-fossil for the base of this interval, occurring on both the eastern and equatorial margins. It is represented in all the basins by the genus *Classopollis*, and by the genus *Brachyphyllum*, representative of the macroflora, in the Cabo Sub-basin (northern portion of the Sergipe-Alagoas Basin).

The Gnetaceae, in particular *E. protensus*, is the second most abundant Gymnospermae family in this interval, present in all studied basins mainly at the upper portion of the interval. The existence of Gnetaceae is suggestive of the maintenance of a hot climate under arid to semi-arid conditions (Herngreen and Dueñas-Jimenez, 1990; Herngreen et al., 1996; Schrank, 2001), which prevailed since at least mid-Albian. Other Gnetaceae are represented by *Sofrepites* (Camamu, Sergipe-Alagoas, Potiguar, Ceará, Barreirinhas, São Luís, and Bragança-Viseu), *Elaterocolpites* (Camamu, Sergipe-Alagoas, Potiguar, Ceará, Barreirinhas, and São Luís), and *Steevesipollenites* (Barreirinhas).

The Ephedraceae occur widely in both the east-margin basins (Camamu and Sergipe-Alagoas) and the equatorial margin (Potiguar, Ceará, Barreirinhas, São Luís, and Bragança-Viseu). The Barreirinhas Basin is the area with the greatest genera diversity (*Ephedripidites*, *Galeacornea*, *Senegalosporites*, *Alaticolpites*, and *Elateroplicites*); only *Elateroplicites* has published records for the other basins.

The Araucariaceae were recorded in the Potiguar, Barreirinhas, and São Luís basins, mainly by the genus *Araucariacites*, with *Araucarites*, a representative of the megaflora, recorded in the Cabo Sub-basin (Sergipe-Alagoas Basin).

The family Cupressaceae (with *Uesuguipollenites*) and the Cycadales (with *Bennettitaepollenites*) have published records only for the Potiguar Basin.

Applanopsis dampieri, considered by some authors as a synonymous of *Callialasporites segmentatus* (Balme, 1957; Srivastava, 1963*in*Raine et al., 2011) was the only record of Podocarpaceae for this interval, occurring exclusively in the Barreirinhas Basin (Regali et al., 1985). The Cabo Sub-basin (Sergipe-Alagoas Basin) has one isolated record of Welwitschiaceae (Barbosa et al., 2008).

The Fabaceae (*Striopollenites*), Didymelaceae (*Hexaporotricolites*), Trimeniaceae (*Cretacaeiporites*) and Winteraceae (*Afropollis*) are the Angiospermae with the wider geographic distribution at this interval, presenting records for Camamu, Sergipe-Alagoas, Potiguar, Ceará, and Barreirinhas basins. The Winteraceae were recorded for Sergipe-Alagoas, Araripe, Potiguar, Ceará, and Barreirinhas basins.

Other isolated records occur as follows: Acanthaceae (*Cornetipollis*), for the Potiguar Basin, Arecaceae (*Retimonocolites*), for Barreirinhas, and Magnoliaceae (*Trifossapollenites*), for the Cabo Sub-basin.

Ferns are still very poorly represented, as they were for the mid- and early Albian. They occur only with the family Marsileaceae in the Barreirinhas (*Perotriletes*) and Bragança-Viseu (*Crybelosporites*) basins.

Lycopods are represented by the genus *Leptolepidites* (Lycopodiaceae) in Camamu, Sergipe-Alagoas, Potiguar, Ceará, and Barreirinhas basins. Bryophytes are represented by the genus *Cingulatisporites* (Anthocerotaceae).

4.6.1. Climate, ecology and paleogeography

The inferences about the phytogeographic distribution for the Brazilian eastern margin are based on the records for the Camamu and Sergipe-Alagoas basins. As was the case for the mid-Albian, there were no specific families representing highland areas in these basins. On the other hand, the presence of vegetation adapted to interior plains (e.g., Ephedraceae and a much-localized occurrence of Welwitschiaceae) and stressful coastal environments, under the marine-evaporitic influence (Cheirolepidiaceae), is suggestive of warm conditions and high aridity (Fig. 9A). Additionally, the presence of lycopods and bryophytes is indicative of the existence of humid environments favorable to the development of these groups, in spite of the very poor representation of Pteridophyta. The existence of internal humid or fluvial-deltaic plains would favored the development of a more diversified vegetation, composed of Gnetaceae, Trimeniaceae, Fabaceae, Didymelaceae, and Winteraceae, containing rare Magnoliaceae, as well as lycopods (Lycopodiaceae) and bryophytes (Anthocerotaceae). In the coastal and humid lowlands, the vegetation would consist of Gnetaceae, Fabaceae, Didymelaceae, Winteraceae, Lycopodiaceae, and Anthocerotaceae, with rare Araucariaceae and Magnoliaceae. The Cheirolepidiaceae would be restricted to zones with higher evaporation along the coast, under conditions stressful for the development of the other groups.

For the equatorial margin, the phytogeographic distribution is based mainly on the records for the Potiguar, Ceará, and Barreirinhas basins. Despite the rare occurrences, and restricted to Barreirinhas, the presence of Podocarpaceae and Cupressaceae could be indicative of the existence of nearby highlands but also that these highlands areas could have been eroded on the other basins (Fig. 9B). Representatives of Ephedraceae, in addition to rare Podocarpacea and Cupressaceae, could also grow on somewhat arid interior plains. Moist areas, such as the interior moist and fluvial-deltaic plains, would have more diverse vegetation, composed of representatives of Winteraceae, Fabaceae, Didymelaceae, Lycopodiaceae, and Anthocerotaceae, with sporadic occurrences of Marsileaceae and Arecaceae. In the former, rare Cupressaceae, Cycadales and Acanthaceae could also occur. In the fluvial–deltaic plains, Trimeniaceae would also occur, with Gnetaceae possible growing in the deltaic areas.

In the coastal, humid lowlands, would grow Gnetaceae, Winteraceae, Fabaceae, Didymelaceae, and rare Araucariaceae, Acanthaceae, Arecaceae, Marsileaceae, Lycopodiaceae, and Anthocerotaceae. The occurrence of

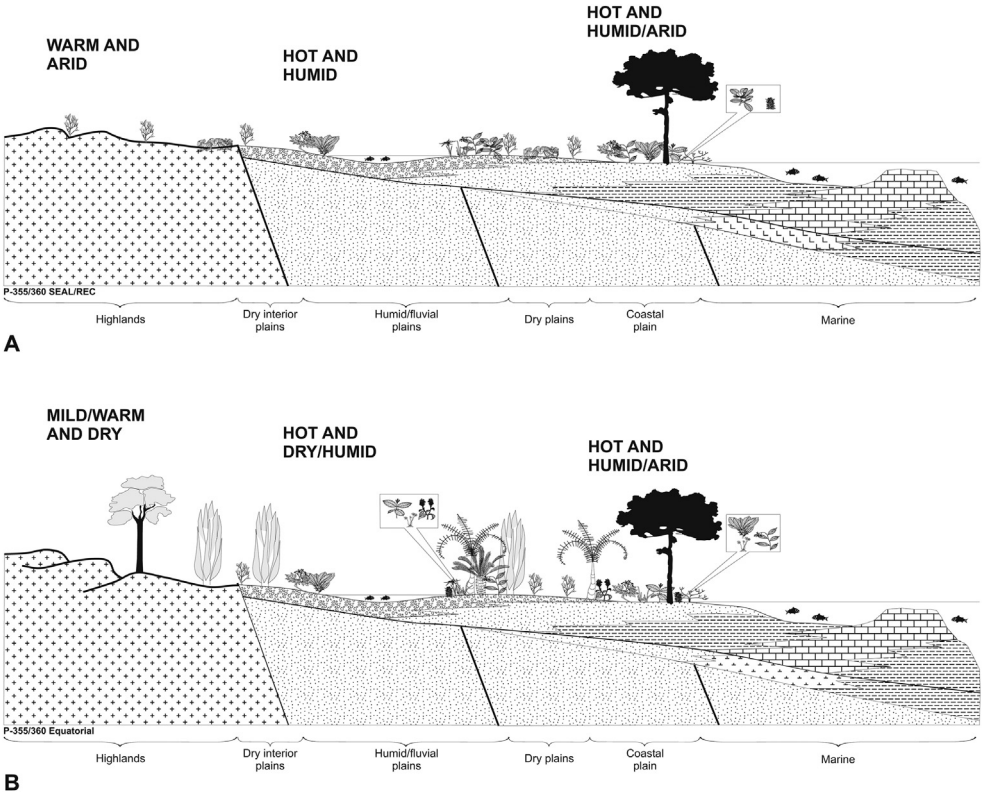

Fig. 9. Schematic transversal paleophytogeographic profiles representing the main vegetation coverage that existed during the late Albian, corresponding to the interval of the palynological zones P-355/P-360. (A) East-margin basins; (B) Equatorial-margin basins.

Cheirolepidiaceae would be restricted to coastal environments subject to greater restriction and evaporation.

5. Conclusions

A comparative analysis of the phytogeographic distribution over the studied interval (upper Aptian–upper Albian) allows making inferences about not only the climatic and ecological changes, but also the physiography of the studied areas.

A more detailed analysis was not possible due to significant differences in the data available for each of the basins per time interval, which would harm the integration and the achievement of reliable conclusions.

During deposition of the lower Aptian section (P-260), highlands with cold to hot, but dry climates probably existed in the Icó Basin region. Despite the existence of more humid interior plains, reflected by the high diversity of Pteridophyta (35 species in 7 known families and 12 undefined), their coastal region would be subject, at least locally, to more stressful conditions. Warmer conditions but not arid, as a whole, prevailed in the area of the current Brazilian eastern margin, being even hotter and arid on the equatorial margin.

It is inferred that highlands still existed in the region of the interior basins, and at the eastern and equatorial margins due to the wide presence of Podocarpaceae, during part of the late Aptian (equivalent to the temporal extension of the P-270 zone). Climatic conditions would generally be hot, but more humid in the inner basins and on the eastern margin, although probably greater in the former, as may be inferred from the high diversity of ferns (especially the Cyatheaceae), lycopods and bryophytes. On the other hand, the conditions would be significantly more arid in the equatorial margin, sometimes extreme, because the extensive presence of Cheirolepidiaceae suggests that, at least locally, there would occur saline coastal environments with stressful characteristics.

From the neo-Aptian (P-280), there are no longer significant records published for the inner basins. For the other regions, the widespread distribution of Podocarpaceae persists, suggesting the existence of highlands, with a milder climate, both on the eastern and equatorial margins. The presence of some families, among them Gnetaceae, Ephedraceae, and Euphorbiaceae, shows that the climate, however, would be warm, locally arid, but with frequently present humid environments, as demonstrated by the high diversity of ferns and, to a lesser extent, lycopods and bryophytes. The record of Cyatheaceae in Barreirinhas is suggestive that the region has undergone a significant increase of the humidity in this interval. The lack of records of Cheirolepidiaceae is indicative of the absence of stressful environments in both margins.

During early Albian, the phytogeographic distribution reflects a significant change in climatic conditions, both on the eastern and equatorial margins, with a marked decrease of humidity, as exemplified by the decrease of Pteridophyta, few occurrences of Lycopodiophyta and no records of Bryophyta. The drastic decrease in Podocarpaceae may indicate reduction or absence of highlands. Podocarpaceae would be a predominantly subtropical to a temperate austral group and its decline would be related to the erosion of colder highlands in the late stages of rift evolution (Doyle et al., 1982). The Cheirolepidiaceae, although localized, in both the eastern and equatorial basins, in addition to the absence of bryophytes, reduced content of lycopods and ferns, and wide distribution of Gnetaceae and Euphorbiaceae (the latter only for the equatorial margin) is suggestive of the predominance of a warmer climate, increased aridity and existence of more stressful environments than those would have existed during the deposition of the upper Aptian section.

For the mid-Albian (equivalent to the amplitude of the P-330 zone), the phytogeographic distribution is suggestive of the absence of highlands for the eastern and equatorial regions. It is assumed, therefore, that higher lands, existing in older times, would have been eroded, with no vegetation coverage significantly different from the other phytoecological contexts in these areas. Climatic conditions would still be predominantly hot and arid, but milder on the eastern margin than on the equatorial margin, where there appears to be increased aridity from east to west, whose apex would be marked by the records of Cheirolepidiaceae in Bragança-Viseu.

The lack of forms indicative of the existence of highlands persists during late Albian (equivalent to the time span of the P-355/P-360 zones). The extensive presence of Cheirolepidiaceae on both eastern and equatorial margins, a wide distribution of Ephedraceae and Gnetaceae, and the presence of Welwitschiaceae in the Cabo Sub-basin suggest the maintenance of arid and hot climate, although it is remarkable the absence of Euphorbiaceae. It is probable that this interval represents the extreme of aridity in all the studied set. The presence of lycopods and bryophytes and the very poorly representation of ferns are suggestive of much localized humid conditions.

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Appendix A. Paleoecological and paleoclimatic inferences of the families whose occurrences are interpreted at the present study

Table A.1
Paleoecological and paleoclimatic inferences of the Gymnospermae families.

Family/order	Paleoecology and paleoclimate
Araucariaceae	Grow in hot and humid lowland or coastal plain (Gary *et al.*, 2009) not subject to aridity in essentially tropical to subtropical conditions (Doyle *et al.*, 1982; Deaf, 2009; Gary *et al.*, 2009) being indicative of a mild climate, turning into arid and cold (Regali & Silva Santos, 1999).
Caytoniaceae	They are indicative of transitional climate from mild to arid and cold, under high altitudes and subtropical conditions (Regali & Silva Santos, 1999; Carvalho, 2001). *Vitreisporites* is indicative of temperate and humid climate, with a preference for fluvial-deltaic plains and wetlands, supporting saline soils (Carvalho, 2001; Gary *et al.*, 2009).
Cheirolepidiaceae	Suggests the existence of dry, hot and arid, stressing environments at coastal areas, growing over carbonatic or relatively saline, dry or waterlogged soils (Pocock & Jansonius, 1961; Médus & Pons, 1967 and Vakhrameev, 1970, 1978, 1980 *in* Alvin 1982; Doyle *et al.*, 1982; Deaf, 2009; Barreda *et al.*, 2012; Portela *et al.*, 2014; Hieger *et al.*, 2015). Abundant in hot and arid climates (Filatoff, 1975 in Alvin 1982).
Coniferae *incertae sedis*[a]	Adapted to mild to a temperate climate, growing on highlands.
Cupressaceae	Indicative of hot, dry climate (Deaf, 2009), probably occurring as typical steppe plain vegetation also in cold and dry climate (Regali & Silva Santos, 1999; Ruiz-Zapata *et al.*, 2010), with preference to wet forests and flooded lands (Leite, 2006).
Cycadales	Suggestive of plains subject to mild and dry climate (Regali & Silva Santos, 1999; Carvalho, 2001; Gary *et al.*, 2009), being characteristic of tropical to subtropical climates in regions with summer rains (Schneider *et al.*, 2002), growing in places with good drainage.
Ephedraceae	Preference for continental, mainly fluvial environments (Lima & Aranha, 1993 in Pedrão *et al.*, 2002). This family normally grow as a steppe vegetation (Ruiz-Zapata *et al.*, 2010), being indicative of an arid climate with a minimum of humidity (Regali & Silva Santos, 1999; Carvalho, 2001; Deaf, 2009), but less tolerant to saline conditions than *Classopollis* (Carvalho, 2001). *Equisetosporites*, *Elateroplicites*, and *Pentapsis* would be adapted to a continental and fluvio-deltaic paleoenvironment in warm, locally humid, with low aridity tolerance areas, in paleo-equatorial regions (Vakhrameev, 1970, 1981 in Pedrão *et al.*, 2002; Srivastava, 1976; Lima, 1976, 1982; Doyle *et al.*, 1982; Lima & Aranha, 1993 in Pedrão *et al.*, 2002; Herngreen *et al.*, 1996; Carvalho, 2001; Zobaa *et al.*, 2013; Portela *et al.*, 2014).
Gnetaceae	Indicative of transitional climate between mild to dry and cold (Regali & Silva Santos, 1999) and well adapted to fluvial-deltaic environments (Vakhrameev, 1970, 1981 *in* Pedrão *et al.*, 2002; Srivastava, 1976; Lima, 1976, 1982). *Sergipea*, *Gnetaceaepollenites*, and *Steevesipollenites* are indicative of a continental, fluvial-deltaic environment in arid and hot climates (Vakhrameev, 1970, 1981 *in* Pedrão *et al.*, 2002; Srivastava, 1976; Lima, 1976, 1982; Lima & Aranha, 1993 in Pedrão *et al.*, 2002; Carvalho, 2001). *Elateropollenites* would have an affinity for areas close to the marine environments and with a salinity level typical of this environment (e.g., paralic, Regali, 1989).
Podocarpaceae	This family would be adapted both to hot and cold climates (Krutzsch, 1971), but growing predominantly in higher and colder areas (Doyle *et al.*, 1982). It is a family predominantly a subtropical to temperate austral group and its decline is related to the erosion of cooler highlands in the final stages of the rift evolution (Doyle *et al.*, 1982). *Caliallasporites*, *Parvisaccites*, and *Rugubivesiculites* indicated a continental and fluvial environment (Lima & Aranha, 1993 in Pedrão *et al.*, 2002) or even lacustrine and estuarine (Hu, 2006), under hot and dry to semiarid conditions (Vallati, 2013).
Ulmanniaceae	Unknown
Welwitschiaceae	A very restrictive family from the paleoclimatic and paleoecological point of view, having preference for desert climate and stressful environments, but may develop over the dry beds of temporary rivers (Doyle *et al.*, 1982; Dilcher *et al.*, 2005), being also well adapted to sandy and marshy regions characterized by environments with evidence of aridity (Doyle *et al.*, 1982).
Williamsoniaceae	It is assumed that they occurred as small shrubs or small trees growing in open areas in nutrient-poor soils (Pott & McLoughlin, 2014).

[a] It is not properly a family but represents the species *Complicatisaccus cearensis* commonly recorded for the Upper Aptian from Northeastern Brazil and until recently, the guide-form for the P-280 palynomorph biostratigraphic zone (Regali, 1989; Carvalho, 2001).

Table A.2
Paleoecological and paleoclimatic inferences of the Angiospermae families.

Family	Paleoecology and paleoclimate
Acanthaceae	Comprise a large family of tropical plants, commonly occurring as vegetation in shaded areas of tropical forests (Givnish, 1984). They are herbaceous, rarely arboreal plants (in this case occurring in mangroves), that live in a diverse number of habitats, helophytic to xerophytic, mainly in a tropical climate (Watson & Dallwitz, 1992-2015).
Aquifoliaceae	Characteristic of dense rainforests and sandbank woodlands (Reitz *et al.*, 1988; Backes & Irgang 2004 in Cancelli *et al.*, 2012). Their growth is associated with lakes, small streams, and rivers, little far from the coast, in temperate and tropical to sub-tropical, but hot climates (Watson & Dallwitz, 1992-2015; Barreda *et al.*, 2012).
Arecaceae	A predominantly subtropical family, growing at hot arid-to-humid climatic conditions (Carvalho, 2001; Leite, 2006; Volkheimer *et al.*, 2007; Barreda *et al.* 2012).
Bignoniaceae	A typical tropical flora family, usually occurring as lianas, although they can also grow at arboreous and shrub, rarely herbaceous, forms (Olmstead *et al.*, 2009; Watson & Dallwitz, 1992-2015).
Cabombaceae	Aquatic, adapted to live in extreme conditions, from arid to hypersaline environments (Lima *et al.*, 2014), growing as herbaceous forms (Mohr *et al.*, 2008).
Calycanthaceae	A family better adapted to paleoequatorial regions, having a herbaceous habit (Mohr & Eklund, 2003).
Circaeasteraceae	Adapted to seasonally dry environments or with a hypersaline substrate, particularly near the coast (Mohr & Rydin, 2002, Mohr *et al.*, 2006).
Chloranthaceae	Arboreous, shrubby or herbaceous plants that grow in humid forests from lower altitudes to the top of the mountains, associated with lakes, small streams or rivers far from the coast (Barreda *et al.*, 2012), under arid and cold to mild climate (Regali & Silva Santos, 1999).
Cyperaceae	Herbaceous habit, growing in a flooded land, although some species tolerate dry and sandy soils, also tolerant to high temperatures (Watson & Dallwitz, 1992-2015; Cancelli *et al.*, 2012).
Didymelaceae	A family represented by perennophile trees that grow in tropical environments (Watson & Dallwitz, 1992-2015).
Euphorbiaceae	A family of shrub plants, although they may have an arboreal habit or grow as lianas, typical of temperate to sub-tropical and tropical climate, supporting

Table A.2 (*continued*)

Family	Paleoecology and paleoclimate
	environments with little water (Watson & Dallwitz, 1992-2015; Deaf, 2009).
Eupomatiaceae	Arboreous or shrubby plants, which grow in temperate and tropical climate (Watson & Dallwitz, 1992-2015).
Fabaceae	Lowland forests components in coastal regions (Germeraad *et al*., 1968; Valero, 2014). They are mesophytic, arboreal or shrub plants, from temperate to tropical climates (Watson & Dallwitz, 1992-2015).
Gunneraceae	Herbaceous to shrubby plants distributed in humid, nitrogen-poor environments of tropical and subtropical regions (Watson & Dallwitz, 1992-2015), usually in high areas, transitioning between arid and cold climate to mild climate, but can also occur in coastal areas (Reitz, 1961; Regali & Silva Santos, 1999).
Liliaceae	A family usually represented by herbaceous, perennial cosmopolitan forms, occurring at different types of environment (Watson & Dallwitz, 1992-2015; Cancelli *et al*., 2012), adapted to dry or humid conditions, including water-edge bodies such as lakes, streams, and rivers, but without body contact, in areas far from the coastline (Watson & Dallwitz, 1992-2015; Scafati *et al*., 2009; Barreda *et al*., 2012).
Magnoliaceae	A much-diversified family that occurs as trees or mesophytic shrubs, perennial or deciduous forms, growing in temperate to tropical climates (Watson & Dallwitz, 1992-2015).
Ranunculaceae	Herbaceous or shrubby plants, sometimes creepers, distributed in temperate to tropical, hydrophytic to mesophytic zones (Watson & Dallwitz, 1992-2015).
Salicaceae	Develop along floodplains and river courses, over point-bars and sandy or gravelly terrains; they are particularly abundant in braided rivers in areas of cold to temperate climate (Watson & Dallwitz, 1992-2015; Nakamura & Inahara, 2007).
Trimeniaceae	A family of arboreal or shrub habit, occurring even as vines, in sub-tropical to tropical climate (Watson & Dallwitz, 1992-2015).
Winteraceae	A family supposed to have grown in coastal and inland areas, possibly being more abundant in the paleo-equatorial humid belt (Doyle *et al*., 1982). *Afropollis* would prefer coastal wetland habitats (Deaf, 2009). Its abundance is usually considered indicative of a warmer but humid climate (Doyle *et al*., 1982).

Table A.3
Paleoecological and paleoclimatic inferences of the Pteridophyta families.

Family	Paleoecology and paleoclimate
Anemiaceae	Essentially terrestrial or epiphytic (Mortara, 2012), growing under locally humid climatic conditions (Deaf, 2009), in tropical and subtropical regions, although they may occur in semi-arid habitats (Germeraad *et al*., 1968; Lorente, 1986, in Valero, 2014).
Cyatheaceae	A family essentially tropical in distribution, and slightly tolerant to water scarcity (Hietz, 2010), indicating humid conditions near the coast (Carvalho, 2001), growing under mild temperatures in a tropical climate (Graham *et al*., 2000). They include the highest known fern-trees, reaching heights of up to 20 meters (Tryon & Tryon, 2012).
Dicksoniaceae	Resembling Cyatheaceae, occur in transitional climate between mild to arid and cold (Regali & Silva Santos, 1999), covering the ground in wet areas (Petersen & Lindstrom,2012), but yet tolerant to regions subject to extreme drought (Portela *et al*., 2014). They are considered opportunistic families, colonizing bare soils or soils disturbed by some natural event (Collinson, 2002).
Dipteridaceae	A family that grew along streams and as a pioneer species. Growing as pedunculated or entangled forms, with broad fronds that, maximizing their light interception area, would allow colonizing and dominating the vegetation in exposed and recently disturbed or sparsely vegetated areas (Nagalingum & Cantrill, 2006). They would occupy sunny and bright places on mountain slopes or cracks in the rocks, also preferring poor-nutrients soils (Tryon and Tryon, 2012; Kramer, 1990a, b).
Equisetaceae	A family with a very broad distribution, from boreal forests to tropical areas, growing in altitudes up to 4200m. They inhabit a wide variety of wet or flooded environments, streams and lakes margins, including degraded soils, often forming dense colonies (Hoffman, 2002; Friis *et al*., 2011).
Gleicheniaceae	Prefer mild, dry climate, developing under plains as soil cover in drier areas of flooded land (Gary *et al*., 2009; Petersen & Lindstrom, 2012). They would occupy sunny and bright places on mountain slopes or cracks in the rocks, also preferring poor-nutrients soils. Could also occur in open areas of moderate altitudes and lowlands. Are considered opportunistic families, colonizing bare soils or soils disturbed by some natural event (Collinson, 2002). Their large fronds maximize light interception, allowing these ferns to colonize and dominate in exposed (i.e., lightly shaded), and recently disturbed (consequently sparsely vegetated) areas (Nagalingum & Cantrill, 2006). They occupy sunny, lightly shaded sites, typically on exposed mountain slopes or rock cuttings also occur in open areas in moderate altitudes and lowland regions (Tryon and Tryon, 2012; Kramer, 1990a, b).
Grammitidaceae	They are important components of tropical forests in mountainous regions, reaching temperate regions of average latitude, with few species occurring in lowland forests as epiphytes on trees or rocks along rivers (Parris, 2003).
Marattiaceae	An exclusively tropical family, occurring mainly in permanently wet forests on well-drained soils. Many actual species seem to prefer steep slopes or creek banks and can be found in lowland rainforests, up to an elevation of about 2000 m (Christenhusz & Tuomisto, 2005).
Marsileaceae	They are plants preferring locally humid climates, growing in freshwater environments (lakes, ponds), wetlands being tolerant to brackish water (Regali, 1989; Deaf, 2009). adapted to hot and arid climate (Portela *et al*., 2014).
Matoniaceae	A family that grows as pedunculated or entangled forms, with broad fronds that, maximizing their light interception area, would allow colonizing and dominating the vegetation in exposed and recently disturbed or sparsely vegetated areas (Nagalingum & Cantrill, 2006). They would occupy sunny and bright places on mountain slopes or cracks in the rocks, also preferring poor-nutrients soils (Tryon and Tryon, 2012; Kramer, 1990a, b).
Osmundaceae	Grow as a ground cover in moist areas having a preference for wet habitats, usually growing on the banks of lakes and peat bogs, especially in freshwater-flooded forests (Collinson, 2002).
Pteridaceae	A family that contains forms adapted to drier regions, supporting semi-arid environments (Sharpe *et al*., 2010).
Salviniaceae	Essentially aquatic, adapted to freshwater environments such as swamps (Volkheimer *et al*., 2007).
Schizaeaceae	Suggests hot and humid climate (Regali & Gonzaga, 1985) in wet or flooded coastal plains (Carvalho, 2001; Gary *et al*., 2009; Scafati *et al*., 2009). Are considered opportunistic families, colonizing bare soils or soils disturbed by some natural event (Collinson, 2002).
Tedeleaceae	Develop under a transitional climate between mild to arid and cold (Regali & Silva Santos, 1999), having a preference for siliciclastic soils along the water bodies Phillips & Galtier, 2011).

Table A.4
Paleoecological and paleoclimatic inferences of the Lycopodiophyta families.

Lycopodiophyta	Paleoecology and paleoclimate
Isoetaceae	Are indicative of the existence of saline soils and arid climate (Friis *et al*., 2011), suggesting a good adaptation to stressful environments (Villanueva-Amadoz *et al*., 2014).
Lycopodiaceae	This family has terrestrial to epiphytes habits, being frequently found next to watercourses or humid tree trunks, which allow them to withstand relatively long periods of drought (Rusea *et al*., 2009; Scafati *et al*., 2009; Petersen & Lindstrom, 2012). Have preferences for tide-influenced environments (Gary *et al*., 2009), also typically occurring as soil cover in damp or wet areas (Scafati *et al*., 2009; Petersen & Lindstrom, 2012) under climate ranging from mild to dry and cold (Regali & Silva Santos, 1999). The presence of *Leptolepidites* and *Retitlettes* are indicative of the transition from arid and cold to mild climates (Regali & Silva Santos, 1999).

(continued on next page)

Table A.4 (*continued*)

Lycopodiophyta	Paleoecology and paleoclimate
Selaginellaceae	Would be indicative of freshwater environments in marshes, also growing as soil cover in damp or wet areas shaded areas (Volkheimer *et al*., 2007; Scafati *et al*., 2009; Petersen & Lindstrom, 2012), under climate ranging from mild to dry and cold (Regali & Silva Santos, 1999). *Densoisporites* were a halophytic form, which could grow in temperate regions under tidal influence (Gary *et al*., 2009).

Table A.5
Paleoecological and paleoclimatic inferences of the Bryophyta families.

Bryophyta	Paleoecology and paleoclimate
Anthocerotaceae	Usually occur scattered along streams and ditches, on disturbed soils after a dry summer and at the edges of springs, normally in the shade of shrubs or trees (Sagar & Wilson, 2007). Prefer moist clay soils; the Sphagnaceae grow preferentially in flooded environments, such as swamps (Volkheimer *et al*., 2007).
Sphagnaceae	A family that has a preference for freshwater environments in flooded areas (Volkheimer *et al*., 2007).
Ricciaceae	Constitute a group of terrestrial bryophytes that contain forms more resistant to a wide variation of temperatures, occurring in areas with dry seasons, including arid regions, growing usually as pioneer vegetation on naked ground, and also on occasionally flooded areas (Mägdefrau, 1982, Ayub *et al*., 2014).

References

Abbink, O.A., 1998. Palynological identification in the Jurassic of the North Sea region. LPP Contrib. Ser. 8, 1–192.

Agarwal, S.K., Tiwari, S., Dubey, P.S., 1996. In: Nagia, S.B. (Ed.), Biodiversity and environment. A. P. H. Publishing Corporation, New Delhi, p. 351.

Alvin, K.L., 1982. Cheirolepidiaceae: biology, structures and paleoecology. Rev. Palaeobot. Palynol. 37, 71–98.

Anderson, C.L., Bremer, K., Friis, E.M., 2005. Dating phylogenetically basal eudicots using RBCL sequences and multiple fossil reference points. Am. J. Bot. 92 (10), 1737–1748.

Antonioli, L., 1998. Estudo palinológico da seção Aptiana-Eoalbiana da Bacia do Ceará-Nordeste do Brasil: sistemática, bioestratigrafia e paleoambientes. Universidade do Estado do Rio de janeiro, UERJ, Rio de Janeiro, Instituto de Geociências. Masters dissertation, p. 107.

Araripe, P. de T., Feijó, F.J., 1995. Bacia Potiguar. Boletim de Geociências da PETROBRAS 8 (11), 127–141 for 1994.

Archangelsky, S., 2008. On the genus Tomaxellia (Coniferae) from the Lower Cretaceous of Patagonia (Argentina) and its male and female cones. J. Linn. Soc. Lond. Bot. 61, 153–165. https://doi.org/10.1111/j.1095-8339.1968.tb00113.x.

Archangelsky, S., Archangelsky, A., 2006. Putative early cretaceous pteridaceous spores from the offshore Austral Basin in Patagonia, Argentina. Cretac. Res. 27, 473–486.

Archangelsky, S., Seoane, L.V.de., 1998. Palynological studies of the Baquero Formation (cretaceous), Santa Cruz Province, Argentina. VIII. Ameghiniana 35 (1), 7–19.

Asmus, H.E.; Ponte, F.C. 1973. The Brazilian marginal basins. In: Nairn, A.E.M. and Stehli, F. G. (eds.), The Ocean Basin and Margins. Plenum Press, New York, 1: 87–133.

Assine, M.L., 2007. Bacia do Araripe. Boletim de Geociências da PETROBRAS 15 (2), 371–389.

Ayub, D.M., Cos, D.P. da, Santos, R.P. dos, 2014. Additions to the Ricciaceae flora of Rio Grande do Sul, including two remarkable records for the Brazilian liverwort flora. Phytotaxa 161 (4), 294–300.

Backes, P., Irgang, B., 2004. Árvores cultivadas no Sul do Brasil: guia de identificação e interesse paisagístico das principais espécies exóticas. Editora Paisagem do Sul, Porto Alegre, p. 205.

Balme, B.E., 1957. Spores and pollen grains from the Mesozoic of Western Australia. Commonwealth Scientific and Industrial Research Organization. Coal Research Section, T. C. 25, Australia, p. 48.

Balme, B.E., 1995. Fossil in situ spores and pollen grains: an annotated catalogue. Rev. Palaeobot. Palynol. 87, 81–323.

Bankhole, S.I., 2010. Palynology and stratigraphy of three deep wells in the Neogene Agbada Formation, Niger Delta, Nigeria. Implications for petroleum exploration and paleoecology. Doctoral thesis. Technischen Universität Berlin, Berlin, p. 135 i-xii. 2 appendices.

Barbosa, J.A., Dutra, T.L., Pereira, J.F., Lima Filho, M., Kerkhoff, M.L., 2008. Primeira ocorrência de restos de plantas em folhelhos do Albiano da bacia de Pernambuco, NE do Brasil. Simpósio de Paleobotânicos e Palinólogos, 12, Florianópolis, Santa Catarina, 2008. Asociación Latinoamericana de Paleobotánica y Palinología, Boletim de Resumos, p. 9.

Barreda, V.D., Cúneo, N.R., Wilf, P., Currano, E.D., Scasso, R.A., Brinkhuis, H., 2012. Cretaceous/Paleogene floral turnover in Patagonia: drop in diversity, low extinction, and a *Classopollis* spike. PLoS One 7 (12), e52455. https://doi.org/10.1371/journal.pone.0052455.

Batten, D.J., 1996. Palynofacies and palaeoenvironmental interpretation. In: Jansonius, J., McGregor, D.C. (Eds.), Palynology: Principles and applications. 3. American Association of Stratigraphic Palynologists Foundation, Salt Lake City, pp. 1011–1064.

Batten, D.J., 2007. Spores and pollen from the Crato formation: Biostratigraphic and palaeoenvironmental implications. In: Martill, D.M., Bechly, G., Loveridge, R.F. (Eds.), The Crato Fossil Beds of Brazil. Cambridge University Press, Cambridge, pp. 566–574.

Bell, C.D., Soltis, D.E., Soltis, P.S., 2010. The age and diversification of the angiosperms re-revisited. Am. J. Bot. 97 (8), 1–8.

Beltrami, C.V., Alves, L.E.M., Feijó, F.J., 1995. Bacia do Ceará. Boletim de Geociências da PETROBRAS 8 (11), 117–125 Rio de Janeiro. for 1994.

Bernardes-de-Oliveira, M.E.C., Mohr, B., Pons, D., Loveridge, R., Ricardi Branco, F., Castro Fernandes, M.C., 2006. Schizaeacean ferns from the Early Cretaceous Crato Formation, Northeast Brazil. European Palaeobotany-Palynology Conference, 7th, Praga, 2006. Program and Abstracts, p. 14.

Beurlen, G., 1982. Bioestratigrafia e geohistória da seção marinha da margem continental brasileira. Boletim Técnico da PETROBRAS 25 (2), 77–83.

Biagolini, C.H., Bernardes-de-Oliveira, M.E.C., Carames, A.G., 2013. Itaquaquecetuba Formation, São Paulo basin, Brazil: new angiosperm components of Paleogene Taphoflora. Braz. J. Geol. 43 (4), 639–652.

Boltenhagen, E., 1975a. Pollen périporé du Crétacé Supérieur du Garbon. Rev. Micropaleontol. 17 (4), 164–170.

Boltenhagen, E., 1975b. Quelques spores du Crétacé supérieur du Gabon. Rev. Micropaleontol. 18 (2), 69–80.

Bradley, R.S., 2013. Paleoclimatology: reconstructing climates of the quaternary. 3th. Edition. Academic Press, Elsevier, Oxford, p. 613.

Bradshaw, R., 1994. Quaternary terrestrial sediments and spatial scale: The limits to interpretation. In: Traverse, A. (Ed.), Sedimentation of Organic Particles. Cambridge University Press, Cambridge, pp. 239–252.

Brandão, J.A.S.L., Feijó, F.J., 1995. Bacia do Pará-Maranhão. Boletim de Geociências da PETROBRAS 8 (11), 101–102 for 1994.

Bussell, M.R., Mildenhall, D.C., 1990. Extinct palynomorphs from middle and late Pleistocene terrestrial sediments, South Wanganui Basin, New Zealand. N. Z. J. Geol. Geophys. 33, 439–447.

Caixeta, J.M., Bueno, G.V., Magnavita, L.P., Feijó, F.J., 1995. Bacias do Recôncavo, Tucano e Jatobá. Boletim de Geociências da PETROBRAS 8 (11), 163–172 for 1994.

Caixeta, J.M., Milhomen, P., Da, S., Witzke, R.E., Dupuy, I.S.S., Gontijo, G.A., 2007. Bacia de Camamu. Boletim de Geociências da PETROBRAS 15 (2), 455–461.

Campos Neto, O.P. de, Souza-Lima, W., Cruz, F.E.G.da., 2007. Bacia de Sergipe-Alagoas. Boletim de Geociências da PETROBRAS 15 (2), 405–415.

Cancelli, R.R., Souza, P.A., Neves, P.C.P., 2012. Grãos de pólen de angiospermas do Holoceno (7908 ± 30 anos AP-atual) da Planície Costeira sul-catarinense, Brasil. Acta Bot. Brasilica 26 (4), 866–885.

Carvalho, M.A., 2001. Paleoenvironmental reconstruction based on palynological and palynofacies analyses of the Aptian-Albian succession in the Sergipe Basin, Northeastern Brazil. PhD thesis. Universität Heidelberg, Geologisch-Paläontologisches Institut, p. 150 6 plates, 4 appendices.

Christenhusz, M.J.M., Tuomisto, H., 2005. Some notes on the taxonomy, biogeography and ecology of *Danaea* (Marattiaceae). The Fern Gazette 17 (4), 217–222.

Churchill, J.M., Poole, M.T., Skarpeid, S.S., Wakefield, M.I., 2017. Stratigraphic architecture of the Knarr Field, Norwegian North Sea: sedimentology and biostratigraphy of an evolving tide- to wave-dominated shoreline system. In: Hampson, G.J., Reynolds, A. D., Kostic M. R., B. and Wells (Eds.), Sedimentology of paralic reservoirs: Recent Advances. Geological Society. 444. Special Publications, London, pp. 35–58.

Collinson, M.E., 2002. The ecology of Cainozoic ferns. Rev. Palaeobot. Palynol. 119, 51–68.

Condé, V.C., Lana, C.C., O. da. C., Pessoa Neto, Roesner, E.H., Morais Neto, J.M. de, Dutra, D. C., 2007. Bacia do Ceará. Boletim de Geociências da PETROBRAS 15 (2), 347–355.

Costa, I.P., Milhomem, P. da S., Bueno, G.V., Lima E Silva, H.S.R., Kosin, M.D., 2007a. Subbacias de Tucano Sul e Central. Boletim de Geociências da PETROBRAS 15 (2), 433–443.

Costa, I.P., Milhomem, P. da S., Bueno, G.V., Lima E Silva, H.S.R., Kosin, M.D., 2007b. Subbacia de Tucano Norte e bacia de Jatobá. Boletim de Geociências da PETROBRAS 15 (2), 445–453.

Couper, R.A., 1953. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. N. Z. Geol. Surv. Palaeontol. Bull. 22, 77.

Deaf, A.S., 2009. Palynology, palynofacies and hydrocarbon potential of the Cretaceous rocks of northern Egypt. PhD thesis. University of Southampton, Faculty of Engineering, Science and Mathematics, School of Ocean and Earth Sciences, p. 348.

Del Fueyo, G.M., Archangelsky, S., 2005. A new araucarian pollen cone with in situ *Cyclusphaera* Elsik from the Aptian of Patagonia, Argentina. Cretac. Res. 26, 757–768.

Dettmann, M.E., 1963. Upper Mesozoic microfloras from Southeastern Australia. Proc. R. Soc. Vict. 77 (1), 1–148.

Dettmann, M.E., 1981. The Cretaceous Flora. In: Keast, A. (Ed.), Ecological biogeography of Australia. W. Junk, The Hague, pp. 357–375.

Dettmann, M.E., 1994. Cretaceous vegetation: The microfossil record. In: Hill, R.S. (Ed.), History of the Australian Vegetation - Cretaceous to Recent. Cambridge University Press, Cambridge, pp. 143–170.
Dettmann, M.E., Clifford, H.T., 1992. Phylogeny and biogeography of *Ruffordia*, *Mohria* and *Anemia* (Schizaeaceae) and *Ceratopteris* (Pteridaceae): evidence from *in situ* and dispersed spores. Alcheringa 16, 269–314.
Dilcher, D.L., Bernardes-de-Oliveira, M.E., Pons, D., Lott, T.A., 2005. Welwitschiaceae from the lower cretaceous of northeastern Brazil. Am. J. Bot. 92 (8), 1294–1310.
Dino, R., 1996. Algumas espécies novas de grãos de pólen do Cretáceo inferior do nordeste do Brasil. Boletim de Geociências da PETROBRAS 8 (2/4), 257–273 for 1994.
Dino, R., Pocknall, D.T., Dettmann, M.E., 1999. Morphology and ultrastructure of elater-bearing pollen from the Albian to Cenomanian of Brazil and Ecuador: implications for botanical affinity. Rev. Palaeobot. Palynol. 105 (3–4), 201–235.
Doyle, J.A., 1999. The rise of angiosperms as seen in the African Cretaceous pollen record. In: Heine, K. (Ed.), Proceedings of the Third Conference on African Palynology, Johannesburg, 1997. Palaeoecology of Africa and the Surrounding Islands. Balkema, Rotterdam, pp. 3–29.
Doyle, J.A., Hotton, C.L., 1991. 9. Diversification of early angiosperm pollen in a cladistic context. In: Blackmore, S., Barnes, S.H. (Eds.), Pollen and spores. Systematic Association Special Volume. 44, pp. 169–195.
Doyle, J.A., Jardiné, S., Doerenkamp, A., 1982. *Afropollis*, a new genus of early angiosperm pollen, with notes on the cretaceous palynostratigraphy and paleoenvironments of Northern Gondwana. Bull. Cent. Rech. Explor. Prod. Elf-Aquitaine 6, 39–117.
Doyle, J.A., Hotton, C.L., Ward, J.V., 1990. Early cretaceous tetrads, zonasulculate pollen, and Winteraceae. II. Cladistic analysis and implications. Am. J. Bot. 77 (12), 1558–1568.
Duarte, L., 1989. Remains of the Lower Cretaceous plants from North-east of Brazil. Congresso Brasileiro de Paleontologia, 11, Curitiba, PR, 1989. Sociedade Brasileira de Paleontologia, Curitiba, Anais, pp. 219–233.
Duarte, L., 1993. Restos de Araucariáceas da Formação Santana - Membro Crato (Aptiano), NE do Brasil. An. Acad. Bras. Cienc. 65 (4), 357–362.
Dutra, T.L., Boardman, D.R., Souza-Lima, W., 2002. Os fósseis da bacia de Sergipe-Alagoas: Os vegetais: as gimnospermas. Phoenix 46, 1–4.
El Beialy, S., El-Soughier, M., Mohsen, S.A., El Atfy, H., 2011. Palynostratigraphy and paleoenvironmental significance of the cretaceous succession in the Gebel Rissu-1 well, north Western Desert, Egypt. J. Afr. Earth Sci. 59, 215–226.
Van Erve, A.W., Mohr, B., 1988. Palynological investigation of the late Jurassic microflora from the vertebrate locality Guimarota coal mine (Leiria, Central Portugal). Neues Jb. Geol. Paläontol. Monat. 1988, 246–262.
Fanton, J.C.M., Ricardi-Branco, F.S., Dilcher, D.L., Campos, A.C.A., Tavares, S.A.S., 2007. Macrofossil inédito de Caytoniales na Formação Crato, Cretáceo Inferior, Bacia do Araripe, NE, Brasil: estudo preliminar. Editora Interciência. 1. Paleontologia: Cenários de Vida, Rio de Janeiro, pp. 177–188.
Feijó, F.J., 1995a. Bacia de Barreirinhas. Boletim de Geociências da PETROBRAS 8 (11), 103–109 for 1994.
Feijó, F.J., 1995b. Bacias de Sergipe e Alagoas. Boletim de Geociências da PETROBRAS 8 (11), 149–161 for 1994.
Ferreira, E.P., Carvalho, M. de A., Lima, H.P., 2008. Associação palinológica do Aptiano-Cenomaniano da bacia de São Luís (norte do Brasil). Simpósio de Paleobotânicos e Palinólogos, 12, Florianópolis, Santa Catarina, 2008. Asociación Latinoamericana de Paleobotánica y Palinología, Boletim de Resumos, p. 70.
Ferreira, N.N., Ferreira, E.P., Carvalho, I.S., Carvalho, M.A., 2010. Análise sedimentológica e palinológica dos depósitos do afloramento Querru, Fm. Itapecuru, Bacia do Parnaíba. In: Carvalho, I.S., et al. (Eds.), Paleontologia: Cenários de Vida. v. 3. Editora Interciência, Rio de Janeiro, pp. 93–103.
Filatoff, J., 1975. Jurassic palynology of the Perth Basin, Western Australia. Palaeontographica, B 154, 1–113.
Frederiksen, N.O., 1980. Sporomorphs from the Jackson Group (Upper Eocene) and adjacent strata of Mississippi and Western Alabama. Geological Survey Professional Paper, 1084, p. 75 16 plates.
Friis, E.M., Crane, P.R., Pedersen, K.R., 2011. Early Flowers and Angiosperm Evolution. Cambridge University Press, New York, p. 585.
Gamerro, J.C., 1965. Morfologia del polen de *Apterocladus lanceolatus* Archang. (Coniferae) de la Formacion Banquero, Provincia de Santa Cruz. Ameghiniana 4, 133–138.
Gary, A.C., Wakefield, M.I., Johnson, G.W., Ekart, D.D., 2009. Application of fuzzy c-means clustering to paleoenvironmental analysis: example from the Jurassic, Central North Sea, UK. In: Demchuk, T.D., Gary, A.C. (Eds.), Geologic Problem Solving with Microfossils: A Volume in Honour of Garry D. Jones. SEPM Special Publication. Vol. 93, pp. 9–20.
Germeraad, J.H., Hopping, C.A., Muller, J., 1968. Palynology of tertiary sediments from tropical areas. Rev. Paleobot. Palynol. 6, 189–348.
Givnish, T.J., 1984. Leaf and canopy adaptations in tropical forests. In: Medina, E., Mooney, H.A., Vázquez-Yánes, C. (Eds.), Physiological Ecology of Plants of the Wet Tropics. Dr W. Junk Publishers, The Hague, pp. 51–84.
Góes, A.M.O., Feijó, F.J., 1995. Bacia do Parnaíba. Boletim de Geociências da PETROBRAS 8 (11), 57–67 for 1994.
Gomez, B., Coiffard, C., Sender, L.M., Martín-Closas, C., Vilanueva-Amadoz, U., Ferrer, J., 2009. *Klitzschophyllites*, aquatic basal eudicots (Ranunculales?) from the Upper Albian (lower cretaceous) of northeastern Spain. Int. J. Plant Sci. 170 (8), 1075–1085.
Graham, A., Duane, C., Areces-Mallea, A., Frederiksen, N.O., 2000. Studies in neotropical paleobotany. XIV. A palynoflora from the middle Eocene Saramaguacán formation of Cuba. Am. J. Bot. 87 (10), 1526–1539.
Halamski, A.T., Kvaček, J., Vajda, V., 2016. Late Cretaceous (Campanian) leaf and palynoflora from southern Skåne, Sweden. In: Kear, B.P., Lindgren, J., Hurum, J.H., Milàn, J., Vajda, V. (Eds.), Mesozoic Biotas of Scandinavia and its Arctic Territories. 434. Geological Society of London, pp. 207–230 Special Publication.
Harris, W.K., 1971. In: Wopfner, H., Douglas, J.G. (Eds.), The Otway Basin of Southeastern Australia. Geological Surveys of South Australia and Victoria Special Bulletin, pp. 67–87 Tertiary stratigraphic palynology, Otway Basin.
Herngreen, G.F.W., 1973. Palynology of Albian-Cenomanian strata of borehole 1-QS-1-MA, State of Maranhão, Brazil. Pollen et Spores 15 (3–4), 514–555.
Herngreen, G.F.W., 1974. Middle Cretaceous palynomorphs from Northeastern Brazil. Results of a palynological study of some boreholes and comparison with Africa and the Middle East. Bull. Sci. Geol. 17 (1–2), 101–116 plates 1-2.
Herngreen, G.F.W., Dueñas-Jimenez, H., 1990. Dating of the cretaceous Une Formation, Colombia and the relationship with the Albian-Cenomanian Africa - South American microfloral province. Rev. Paleobot. Palynol. 66, 345–359.
Herngreen, G.F.W., Kedves, M., Rovnina, L.V., Smirnova, S.B., 1996. Cretaceous Palynofloral Provinces: a review. In: Jansonius, J., Mcgregor, D.C. (Eds.), Palynology: Principles and Applications. Vol. 3. American Association of Stratigraphic Palynologic Foundation, pp. 1157–1188 Chapter 29C.
Hieger, T.J., Serbet, R., Harper, C.J., Taylor, T.N., Taylor, E.L., Gulbranson, E.L., 2015. Cheirolepidiaceous diversity: an anatomically preserved pollen cone from the lower Jurassic of southern Victoria Land, Antarctica. Rev. Palaeobot. Palynol. 220, 78–87.
Hietz, P., 2010. Fern adaptations to xeric environments. In: Mehltreter, K., Walker, L.R., Sharpe, J.M. (Eds.), Fern Ecology. Cambridge University Press, Cambridge, pp. 140–176.
Hochuli, P.A., Feist-Burkhardt, S., 2013. Angiosperm-like pollen and *Afropollis* from the Middle Triassic (Anisian) of the Germanic Basin (Northern Switzerland). Front. Plant Sci. 4, 1–14 article 344.
Hoffman, G.I., 2002. Paleobotany and paleoecology of the Joffre Bridge roadcut locality (Paleocene), Red Deer, Alberta. Masters Dissertation. University of Alberta, Faculty of Graduate Studies and Research, p. 114.
Holmes, P.L., 1994. The sorting of spores and pollen by water: experimental and field evidence. In: Traverse, A. (Ed.), Sedimentation of Organic Particles. Cambridge University Press, Cambridge, pp. 9–32.
Hu, S., 2006. Palynomorphs and selected mesofossils from the Cretaceous Dakota Formation, Minnesota, USA. Doctoral Thesis. University of Florida, Graduate School, p. 217.
Jackson, S.T., 1994. Pollen and spores in quaternary lake sediments as sensors of vegetation composition: theoretical models and empirical evidence. In: Traverse, A. (Ed.), Sedimentation of Organic Particles. Cambridge University Press, Cambridge, pp. 253–286.
Jain, K.P., 1969. Morphology and taxonomy of the genus Triangulopsis Doring, 1961. The Palaeobotanists 17, 43–47.
Jaramillo, C.A., Rueda, M., Torres, V., 2011. A palynological zonation for the Cenozoic of the Llanos and Llanos Foothills of Colombia. Palynology 35 (1), 46–84.
Jardiné, S., Magloire, H., 1965. Palynologuie et Stratigraphie du Crétacé Des Bassin du Sénégal et Cote d'Ivoire. Mémoires du Bureau de Recherches Géologiques et Miniéres. Vol. 32 pp. 187–245.
Kerkhoff, M.L., Dutra, T.L., 2008. Formas de Gnetales para a Formação Santana, Chapada do Araripe, CE: Novos elementos que ampliam a ocorrência deste grupo de plantas. Simpósio de Paleobotânicos e Palinólogos, 12, Florianópolis, Santa Catarina, 2008. Asociación Latinoamericana de Paleobotánica y Palinología, Boletim de Resumos, p. 107.
Kramer, K.U., 1990a. Gleicheniaceae. In: Kramer, K.U., Green, P.S. (Eds.), Pteridophytes and Gymnosperms. The Families and Genera of Vascular Plants vol. I. Springer-Verlag, Berlin, pp. 145–152.
Kramer, K.U., 1990b. Matoniaceae. In: Kramer, K.U., Green, P.S. (Eds.), Pteridophytes and Gymnosperms. The Families and Genera of Vascular Plants vol. I. Springer-Verlag, Berlin, pp. 183–185.
Krutzsch, W., 1971. Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen- sowie der Mikroplanktonformen des nördlichen Mitteleuropas. Lieferung VI: Coniferenpollen. Gustav Fischer Verlag, Jena, Germany, p. 234 74 pls.
Kubitzki, K., Rohwer, J.G., Bittrich, V., 1993. Vol. II. Flowering plants, Dicotyledons. Magnoliid, Hamamelid and Caryophyllid Families. In: Kubitzki, K. (Ed.), 1990–2004. The Families and Genera of Vascular Plants. Springer-Verlag, Berlin, p. 653.
Kunzmann, L., Mohr, B.A.R., Bernardes-de-Oliveira, M.E.C., 2004. Gymnosperms from the lower cretaceous Crato Formation (Brazil). I. Araucariaceae and *Lindleycladus* (*incertae sedis*). Fossil Record 7 (1), 155–174.
Kunzmann, L., Mohr, B.A.R., Bernardes-de-Oliveira, M.E.C., 2006. Gymnosperms from the early cretaceous crato formation (Brazil). II. Cheirolepidiaceae. Fossil Record 9 (2), 213–225.
Kunzmann, L., Mohr, B.A.R., Bernardes-de-Oliveira, M.E.C., 2007. *Novaolindia dubia* gen. Nov. et sp. nov., an enigmatic seed plant from the early cretaceous of northern Gondwana. Rev. Palaeobot. Palynol. 147, 94–105.
Kunzmann, L., Mohr, B.A.R., Wilde, V., Bernardes-de-Oliveira, M.E.C., 2011. A putative gnetalean gymnosperm *Cariria orbiculiconiformis* from the early cretaceous of northern Gondwana. Rev. Palaeobot. Palynol. 165, 75–95.
Kustatscher, E., Van Konijnenburg-Van Cittert, J.H.A., Roghi, G., 2010. Macrofloras and palynomorphs as possible proxies for palaeoclimatic and palaeoecological studies: A case study from the Pelsonian (Middle Triassic) of Kühwiesenkopf/Monte Prà della Vacca (Olang Dolomites, N-Italy). Palaeogeogr. Palaeoclimatol. Palaeoecol. 290, 71–80.
Legrand, J., Pons, D., Terada, K., Yabe, A., Nishida, H., 2013. Lower cretaceous (Upper Barremian-lower Aptian?) Palynoflora from the Kitadani Formation (Tetori Group, Inner Zone of Central Japan). Paleontol. Res. 17 (3), 201–229.
Leite, F.P.R., 2006. Palinologia da Formação Solimões, Neógeno da bacia do Solimões, Estado do Amazonas, Brasil: implicações paleoambientais e bioestratigráficas. Doctoral Thesis. Universidade de Brasília, Instituto de Geociências, p. 128.
Lima, M.R., 1976. O gênero *Classopollis* e as bacias mesozóicas do Nordeste do Brasil. Ameghiniana 13 (3/4), 226–234.
Lima, M.R., 1982. Palinologia da Formação Codó na região de Codó, Maranhão. Boletim do Instituto de Geociências. USP 1/4, 116–128.

Lima, M.R., 1984a. Palinologia do linhito de Jatobá (Cretáceo do Nordeste do Brasil). I – Introdução, contexto estratigráfico, identificação de espécies cretáceas. Congresso Brasileiro de Geologia, 33, Rio de Janeiro, RJ, 1984. Sociedade Brasileira de Geologia, Rio de Janeiro, Anais, pp. 536–547.
Lima, M.R., 1984b. Palinologia do linhito de Jatobá (Cretáceo do Nordeste do Brasil). II – Retrabalhamento devoniano, discussão e conclusões. Congresso Brasileiro de Geologia, 33, Rio de Janeiro, RJ, 1984. Sociedade Brasileira de Geologia, Rio de Janeiro, Anais, pp. 551–562.
Lima, M.R., 1990. Estudo palinológico de sedimentos da bacia de Icó, Cretáceo do Estado do Ceará, Brasil. Boletim do Instituto de Geociências, USP, Sér. Cient. 21, 35–46.
Lima, H.P., Aranha, L.G.F., 1993. Bacias de Bragança-Viseu, São Luís e Graben de Ilha Nova: análise integrada, perspectivas e direcionamento exploratório. PETROBRAS, Belém, technical report. 87.
Lima Filho, M. de, Silva Santos, P.R., 2001. Biocronoestratigrafia da Bacia Pernambuco – implicações ambientais e paleogeográficas. Rev. Brasil. Paleontol. 2, 84–85.
Lima, H.P., Aranha, L.G.F., Feijó, F.J., 1995. Bacias de Bragança-Viseu, São Luís e *Graben* de Ilha Nova. Boletim de Geociências da PETROBRAS 8 (11), 111–116 for 1994.
Lima, C.T., Santos, F.A.R., Giulietti, A.M., 2014. Morphological strategies of *Cabomba* (Cabombaceae), a genus of aquatic plants. Acta Bot. Brasil. 28 (3), 327–338.
Lorente, M.A., 1986. Palynology and palynofacies of the Upper Tertiary in Venezuela. Dissertationes Botanicae, 99, p. 222.
Mabesoone, J.M., Campanha, V.A., 1974. Caracterização litoestratigráfica dos Grupos Rio do Peixe e Igatu. Estudos sedimentológicos 3/4 (22), 41.
Mägdefrau, K., 1982. Tropical forest bryophytes. In: Smith, A. (Ed.), Bryophyte Ecology. Chapman and Hall, New York, pp. 59–104.
Mander, L., Kürschner, W.M., Mcelwain, J.C., 2010. An explanation for conflicting records of Triassic-Jurassic plant diversity. PNAS 107 (35), 15351–15356. www.pnas.org/cgi/doi/10.1073/pnas.
Marchant, R., Almeida, L., Behling, H., Berrio, J.C., Bush, M., Cleef, A., Duivenvoorden, J., Kapelle, M., Oliveira, P., De; Oliveira-Filho, A.T., Lozano-Garcia, S., Hooghiemstra, H., Ledru, M.P., Ludlowwierchers, B., Markgraf, V., Mancini, V., Paez, M., Prieto, A., Rangel, O., Salgado-Labouriau, M.L., 2002. Distribuition and ecology of parent taxa of pollen lodged within the Latin American Pollen Database. Rev. Palaeobot. Palynol. 121, 1–75.
Marmi, J.; Martín-Closas, C.; Fernández-Marron, M. T.; Gomez, B. 2016. Latest cretaceous plant landscapes from northeastern Iberia. In: Khosla, A. and Lucas, S. G. (eds.), Cretaceous Period: Biotic Diversity and Biogeography. New Mexico Museum of Natural History and Science, Bulletin, 71: 215–229.
Martill, D.M., Bechly, G., Loveridge, R.F. (Eds.), 2007. The Crato Fossil Beds of Brazil. Cambridge University Press, New York, p. 674.
Martínez, M.A., Prámparo, M.B., Quattrocchio, M.E., Zavala, C.A., 2008. Depositional environments and hydrocarbon potential of the Middle Jurassic Los Molles Formation, Neuquén Basin, Argentina: palynofacies and organic geochemical data. Rev. Geol. Chile 35 (2), 279–305.
Médus, J., Pons, A., 1967. Étude palynologique du Crétacé Pyrénéo-Provençal. Rev. Palaeobot. Palynol. 2, 111–117.
Meyen, S.V., 2012. Fundamentals of Palaeobotany. Chapman and Hall, New York, p. 432 xxi.
Mitra, M., 2002. Paleopalynology of the Tar Heel Formation of Atlantic Coastal Plain of North Carolina, United States. Doctoral Thesis. North Carolina State University, Raleigh, p. 285.
Mohr, B.A.R., Bernardes-de-Oliveira, M.E.C., 2004. *Endressinia brasiliana*, a magnolialean angiosperm from the lower cretaceous Crato Formation (Brazil). Int. J. Plant Sci. 165 (6), 1121–1133.
Mohr, B.A.R., Eklund, H., 2003. *Araripia florifera*, a magnoliid angiosperm from the lower cretaceous Crato Formation (Brazil). Rev. Palaeobot. Palynol. 126 (3–4), 279–292.
Mohr, B.A., Rydin, C., 2002. *Trifurcatia flabellate* n. Gen. n. Sp., a putative monocotyledon angiosperm from the lower cretaceous Crato Formation (Brazil). Mitteilung aus dem Museum fur Naturkunde Berlin, Geowissenschaftliche Reihe 5, 335–344.
Mohr, B.A.R., Bernardes-de-Oliveira, M.E.C., Barale, G., Ouaja, M., 2006. Palaeogeographic distribution and ecology of *Klitzschophyllites*, an early cretaceous angiosperm in southern Laurasia and northern Gondwana. Cretac. Res. 27 (3), 464–472.
Mohr, B.A., Bernardes-de-Oliveira, M.E.C., Taylor, D.W., 2008. *Pluricarpellatia*, a nymphaealean angiosperm from the lower cretaceous of northern Gondwana (Crato Formation, Brazil). Taxon 57 (4), 1147–1158.
Mortara, S., 2012. Universidade de São Paulo, Curso de Pós-Graduação em Ecologia - Prática de pesquisa em ecologia da mata atlântica, São Paulo. p. 4 Riqueza de samambaias epífitas e terrestres em matacões de diferentes alturas).
Nagalingum, N.S., 2007. Marsileaceaephyllum, a new genus for marsileaceous macrofossils: leaf remains from the early cretaceous (Albian) of southern Gondwana. Plant Syst. Evol. 264, 41–55.
Nagalingum, N.S., Cantrill, D.J., 2006. Early cretaceous Gleicheniaceae and Matoniaceae (Gleicheniales) from Alexander Island, Antarctica. Rev. Palaeobot. Palynol. 138, 73–93.
Nair, P.K.K., 1968. A concept on the pollen evolution of primitive angiosperms. J. Palynol. 4 (1), 15–20.
Nakamura, F., Inahara, S., 2007. Fluvial geomorphic disturbances and life history traits of roparian tree species. In: Johnson, E.A., Miyanishi, K. (Eds.), Plant Disturbance Ecology: The Process and the Response. Elsevier, Academic Press, Burlington, pp. 283–310.
Netto, A.S.T., Wanderley Filho, J.W., Feijó, F.J., 1995. Bacias de Jacuípe, Camamu e Almada. Boletim de Geociências da PETROBRAS 8 (11), 173–184 for 1994.
Nichols, D.J., Brown, J.L., 1992. Palynostratigraphy of the Tullock Member (Lower Paleocene) of the Fort Union Formation in the Powder River Basin, Montana and Wyoming. U.S. Geological Survey Bulletin, 1917-F, p. 35 10 plates.
Olmstead, R.G., Zjhra, M.L., Lohmann, L.G., Grose, S.O., Eckert, A.J., 2009. A molecular phylogeny and classification of Bignoniaceae. Am. J. Bot. 96 (9), 1731–1743.
Osborn, J.M., Taylor, T.N., Lima, M.R.de., 1993. The ultrastructure of fossil ephedroid pollen with gnetalean affinities from the lower cretaceous of Brazil. Rev. Palaeobot. Palynol. 77, 171–184.
Pais, J., 1992. Contributions to the Eocene paleontology and stratigraphy of Beira Alta, Portugal. III - Eocene plant remains from Naia and Sobreda (Beira Alta, Portugal). Ciências da Terra 11, 91–108.
Parris, B.S., 2003. The distribution of Grammitidaceae (Filicales) inside and outside Malesia. Telopea 10 (1), 451–466.
Pedrão, E., Lima, H.P., Makino, R.K., Barrilari, I.M.R., 2002. Palinoestratigrafia e evolução ambiental da seção cretácea das bacias de Bragança-Viseu e São Luís (margem equatorial brasileira). Acta Geol. Leopodensia 25 (54), 21–39.
Pessoa Neto, O. da C., Soares, U.M., Silva, J.G.F. da, Roesner, E.H., Florencio, C.P., Souza, C.A. V. de, 2007. Bacia Potiguar. Boletim de Geociências da PETROBRAS 15 (2), 357–369.
Petersen, H.L., Lindstrom, S., 2012. Synchronous wildfire activity rise and mire deforestation at the Triassic–Jurassic boundary. PLoS One 7 (10), 15.
Petersen, H.I., Nielsen, L.H., Koppelhus, E.B., Sorensen, H., 2003. Early and Middle Jurassic mires of Bornholm and the Fennoscandian Border Zone: a comparison of depositional environments and vegetation. Geol. Surv. of Denmark and Greenland Bull. 1, 631–656.
Phillips, T.L., Galtier, J., 2011. Evolutionary and ecological perspectives of late Paleozoic ferns: Part II. The genus *Ankyropteris* and the Tedeleaceae. Rev. Palaeobot. Palynol. 164 (1–2), 1–29.
Pierce, R.L., 1961. Lower Upper cretaceous plant microfossils from Minnesota. The University of Minnesota Press, Minneapolis. Minnesota Geol. Surv. Bull. 42, 86.
Pocock, S.A.J., 1970. Palynology of the Jurassic sediments of western Canadá. Palaeontographica, B 130, 12–136.
Pocock, S.J., Jansonius, J., 1961. The pollen genus *Classopollis* Pflug, 1953. Micropaleontology 7 (4), 439–449.
Pocock, S.A.J., Vasanthy, G., 1988. *Cornetipollis reticulata*, a new pollen with angiospermid features from the upper Triassic (Carnian) sediments of Arizona (U.S.a.), with notes on Equisetosporites. Rev. Palaeobot. Palynol. 55, 337–356.
Ponte, F.C., 1992. Origem e evolução das pequenas bacias cretácicas do interior do Nordeste do Brasil. Simpósio sobre as bacias cretácicas Brasileiras, 2, Rio Claro, São Paulo, 1992. UNESP, Resumos Expandidos, pp. 55–58.
Portela, H.A., Antonioli, L., Dino, R., 2014. Caracterização palinoflorística e paleoambiental da Formação Santana (Cretáceo inferior), poço 4-BO-1-PE, bacia do Araripe, Nordeste do Brasil. Rev. Brasil. Paleontol. 17 (3), 363–372.
Potonié, R., 1975. Beitrage Zur Sporologie. Fortschritte in der Geologie von Rheinland Und Westfalen. Vol. 25 pp. 1–282.
Pott, C., McLoughlin, S., 2014. Divaricate growth habit in Williamsoniaceae (Bennettiales): Unravelling the ecology of a key Mesozoic plant group. Palaeobiodiv. Palaeoenviron. 94 (2), 307–325.
Prentice, I.C., 1985. Pollen representation, source area, and basin size - toward a unified theory of pollen analysis. Quat. Res. 23, 76–86.
Raine, J. I.; Mildenhall, D. C.; Kennedy, E. M. 2011. New Zealand fossil spores and pollen: an illustrated catalogue. 4th edition. GNS Science miscellaneous series, 4. http://data.gns.cri.nz/sporepollen/index.htm. (last access on October, 23, 2017).
Regali, M.S.P., 1986. Palinoestratigrafia do Cretáceo em bacias do Norte e Nordeste do Brasil. Congresso Brasileiro de Geologia, 34, 1986, Goiânia, GO. 1. Sociedade Brasileira de Geologia, Anais, pp. 122–130.
Regali, M.S.P., 1987a. O gênero *Sergipea* e a sua estratigrafia no Eocretáceo do Brasil. Congresso Brasileiro de Paleontologia, 10, Rio de Janeiro, 1987. 2. Sociedade Brasileira de Paleontologia, Rio de Janeiro, Anais, pp. 615–623.
Regali, M.S.P., 1987b. O gênero *Afropollis*, Doyle, Jardiné et Doerenkamp, 1982 e sua distribuição no Cretáceo do Brasil. Congresso Brasileiro de Paleontologia, 10, Rio de Janeiro, 1987. Vol. 2. Sociedade Brasileira de Paleontologia, Rio de Janeiro, Anais, pp. 625–635.
Regali, M.S.P., 1987c. Palinomorfos do Barremiano/Albiano brasileiros. Parte II. Congresso Brasileiro de Paleontologia, 10, Rio de Janeiro, 1987. 2. Sociedade Brasileira de Paleontologia, Rio de Janeiro, Anais, pp. 647–655.
Regali, M.S.P., 1989. *Complicatisaccus cearensis*: uma palinozona do Eocretáceo do Brasil. Congresso Brasileiro de Palentologia, 11, Curitiba, PR, 1989. Sociedade Brasileira de Paleontologia, Curitiba, Anais, pp. 235–274.
Regali, M.S.P., 1995. Palinoestratigrafia do Neoaptiano/Albiano da bacia de Sergipe/Alagoas Brasil. Congresso Brasileiro de Paleontologia, 14, Uberaba, Minas Gerais, 1995. Sociedade Brasileira de Paleontologia, Rio de Janeiro, Atas, pp. 105–106.
Regali, M.S.P., Gonzaga, S.M., 1985. Palinocronoestratigrafia da bacia Potiguar - Rio Grande do Norte, Brasil. Departamento Nacional da Produção Mineral, Coletânea de Trabalhos Paleontológicos. Série Geologia, 27 2. Seção Paleontologia e Estratigrafia, pp. 443–460.
Regali, M.S.P., Silva Santos, P.R., 1999. Palinoestratigrafia e geocronologia dos sedimentos albo-aptianos das bacias de Sergipe e de Alagoas – Brasil. In: Dias-Brito, D., Castro, J.C. de, Rohn, R. (Eds.), Boletim Do 5° Simpósio Sobre O Cretáceo Do Brasil/1er Simposio Sobre el Cretácico de América del Sur, Serra Negra, São Paulo, Brasil, 1999, pp. 411–419.
Regali, M.S.P., Uesugui, N., Santos, A.Da.S., 1974. Palinologia dos sedimentos mesocenozóicos do Brasil (I). Boletim Técnico da PETROBRÁS 17 (3), 177–191.
Regali, M.S.P., Uesugui, N., Santos, A. da S., 1975. Palinologia dos sedimentos mesocenozóicos do Brasil (II). Boletim Técnico da PETROBRÁS 17 (4), 263–301 for 1974. plates 1–25.
Regali, M.S.P., Uesugui, N., Lima, E.C., 1985. Palinocronoestratigrafia e paleoambiente da da bacia de Barreirinhas – Maranhão, Brasil. Departamento Nacional da Produção Mineral, Coletânea de Trabalhos Paleontológicos. Série Geologia, 27 2. Seção Paleontologia e Estratigrafia, pp. 461–480.
Reitz, R., 1961. Vegetação da zona marítima de Santa Catarina. Sellowiana 13 (13), 17–115.

Reitz, R., Klein, R.M., Reis, A., 1988. Projeto Madeira do Rio Grande do Sul. Secretaria de Agricultura e Abastecimento, Sudesul, Porto Alegre, p. 528.
Retallack, G.J., Dilcher, D.L., 1988. Reconstructions of selected seed ferns. Missouri Bot. Garden Ann. 75, 1010–1057.
Ricardi-Branco, F., Torres, M., Tavares, S.S., Carvalho, I. de S., Tavares, P.G.E., Campos, A.C. A., 2013. *Itajuba yansanae* gen. and sp. nov. of Gnetales, Araripe Basin (Albian-Aptian) in Northeast Brazil. In: Zhang, Y., Ray, P. (Eds.), Climate Change and Regional/Local Responses. Intech, pp. 187–205.
Rios-Netto, A.M., Regali, M.S.P., Caravalho, I.S., Freitas, F.I., 2012. Palinoestratigrafia do intervalo Alagoas da Bacia do Araripe, Nordeste do Brasil. Rev. Brasil. Geociên. 42 (2), 331–342.
Rodovalho, N., Gontijo, R.C., Santos, C.F., Milhomen, P., Da, S., 2007. Bacia de Cumuruxatiba. Boletim de Geociências da PETROBRAS 15 (2), 485–491.
Ruiz-Zapata, B., Gil-García, M.J., Bustamonte, I., 2010. Paleoenvironmental reconstruction of Las Tablas de Daimiel and its evolution during the Quaternary Period. In: Sánchez-Carrillo, S., Angeler, D.G. (Eds.), Ecology of Threatened Semi-Arid Wetlands: Long-Term Research in Las Tablas de Daimiel. Springer Science+Business Media B.V., pp. 23–43 https://doi.org/10.1007/978-90-481-9181-9_2.
Rusea, G., Claysius, K., Runi, S., Joanes, U., Haja Maideen, K.M., Latiff, A., 2009. Ecology and distribution of Lycopodiaceae Mirbel in Malaysia. Blumea 54, 269–271.
Rydin, C., Mohr, B.A.R., Friis, E.M., 2003. *Cratonia cotyledon* gen. et sp. nov.: a unique cretaceous seedling related to *Welwitschia*. Proc. R. Soc. Lond. Ser. B 270, S29–S32.
Sá, N. de P., Carvalho, M. de A., 2017. Miocene fern spores and pollen grains from the Solimões Basin, Amazon Region, Brazil. Acta Bot. Brasil. 31 (4), 720–735.
Sagar, T.; Wilson, P. 2007. Bryophytes of the Santa Monica Mountains. In: Knapp, D. A. (Ed.), Flora and Ecology of the Santa Monica Mountains. Southern California Botanists, Fullerton, CA, pp. 63–69, 11 plates.
Santos, C.F., Gontijo, R.C., Araújo, M.B., Feijó, F.J., 1995. Bacias de Cumuruxatiba e Jequitinhonha. Boletim de Geociências da PETROBRAS 8 (11), 185–190 for 1994.
Scafati, L., Melendi, D.L., Volkheimer, W., 2009. A Danian subtropical lacustrine palynobiota from South America (Bororó Formation, San Jorge Basin, Patagonia – Argentina). Geol. Acta 7 (1–2), 35–61.
Schneider, D., Wink, M., Sporer, F., Lounibos, P., 2002. Cycads: their evolution, toxins, herbivores and insect pollinators. Naturwissenschaften 89, 281–294.
Schrank, E., 2001. Paleoecological aspects of *Afropollis*/Elaterates peaks (Albian-Cenomanian pollen) in the Cretaceous of Northern Sudan and Egypt. In: Goodman, D.K., Clarke, R.T. (Eds.), Proceedings of the IX International Palynological Congress, Houston, Texas, U.S.A., 1996. American Association of Stratigraphic Palynologists Foundation, Dallas, pp. 201–210.
Selling, O.H., 1944. Studies in recent and fossil species of Schizaea, with particular reference to their spore characters. Meddelelser från Götebörgs Botaniska Trädgård 16, 112.
Sharpe, J.M., Mehltreter, K., Walker, L.R., 2010. Ecological importance of ferns. In: Mehltreter, K., Walker, L.R., Sharpe, J.M. (Eds.), Fern Ecology. Cambridge University Press, New York, pp. 1–21.
Silva, O.B., Da; Caixeta, J.M., Milhomen, P., Da, S., Kosin, M.D., 2007. Bacia do Recôncavo. Boletim de Geociências da PETROBRAS 15 (2), 423–431.
Singh, C., 1971. Lower cretaceous microflora of the Peace River area, northwestern Alberta. Res. Coun. Alberta Bull. 28 (542 p).
Skog, J.E., 1982. *Pelletixia amelguita*, a new species of fossil fern in the Potomac Group (lower cretaceous). Am. Fern J. 72, 115–121.
Soares, E.F., Zalán, P.V., Figueiredo, J. de J.P., Trosdtorf Jr., I., 2007. Bacia do Pará-Maranhão. Boletim de Geociências da PETROBRAS 15 (2), 321–329.
Souza-Lima, W., 2006. Litoestratigrafia e evolução Tectono-Sedimentar da bacia de Sergipe-Alagoas: Introdução. Phoenix 89, 1–10.
Srivastava, S.K., 1963. Polospores from Jurassic of Rajasthan, India. Nature 198 (4887), 1323–1324.
Srivastava, S.K., 1967. Ephedralean pollen from the Upper cretaceous Edmonton Formation of Alberta (Canada) and their paleoecological significance. Can. J. Earth Sci. 5, 211–221.
Srivastava, S.K., 1972. Systematic description of some spores from the Edmonton Formation (Maestrichtian), Alberta, Canada. Palaeontogr. Abteilung B 139, 1–46.
Srivastava, S.K., 1976. The fossil pollen genus *Classopollis*. Lethaia 9, 437–457.
Stewart, W.N., Rothwell, G.W., 1993. Paleobotany and the Evolution of Plants. Cambridge University Press, New York, p. 521.
Stover, L.E., 1964. Cretaceous Ephedroid Pollen from West Africa. Micropaleontolgy 10 (2), 145–156.
Streel, M., Richelot, C., 1994. Wind and water transport and sedimentation of miospores. In: Traverse, A. (Ed.), Sedimentation of Organic Particles. Cambridge University Press, Cambridge, pp. 59–67.
Takahashi, K., 1997. Fossil spores and pollen grains of cretaceous (Upper Campanian) from Sakhalin, Russia. J. Plant Res. 110, 283–298.
Takahashi, K., Sugiyama, R., 1990. Palynomorphs from the Santonian Uge Member of the Taneichi Formation, Northeast Japan. Bulletin of the Faculty of Liberal Arts, Nagasaki University. Nat. Sci. 30 (2), 133–573.
Taylor, T.N., 1990. Microsporogenesis in Fossil Plants. In: Blackmore, S., Knox, R.B. (Eds.), Microspores – Evolution and Ontogeny. Academic Press, The University Press, Cambridge, pp. 121–145.
Taylor, M.L., Gutman, B.L., Melrose, N.A., Ingraham, A.M., Schwartz, J.A., Osborn, J.M., 2008. Pollen and anther ontogeny in *Cabomba caroliniana* (Cabombaceae, Nymphaeales). Am. J. Bot. 95, 399–413.
Thomson, P.W., Pflug, H., 1953. Pollen und Sporen des mitteleuropäischen. Tertiärs. Palaeontogr., B 94, 1–138.
Tomé, M.E.T.R., Filho, Lima, De, M.F., Neumann, V.H. de M.L., 2006. Análise estratigráfica do Albiano-Turoniano da bacia de Pernambuco: considerações sobre a paleogeografia e geração de hidrocarbonetos. Geociências 25 (1), 49–58.
Traverse, A., 1994. Sedimentation of land-derived palynomorphs in the Trinity-Galveston Bay area, Texas. In: Traverse, A. (Ed.), Sedimentation of Organic Particles. Cambridge University Press, Cambridge, pp. 69–87.
Trosdtorf Jr., I., Zalán, P.V., Figueiredo, J. de J.P., Soares, E.F., 2007. Bacia de Barreirinhas. Boletim de Geociências da PETROBRAS 15 (2), 331–339.
Tryon, R.M., Tryon, A.F., 1982. Ferns and Allied Plants: With Special Reference to Tropical America. Springer Verlag, New York, p. 858.
Tyson, R.V., 1995. Sedimentary Organic Matter. Chapman and Hall, London, p. 615.
Upchurch Jr., G.R., Crane, P.R., Drinnan, A.N., 1994. The Megaflora from the Quantico Locality (Upper Albian), Lower Cretaceous Potomac Group of Virginia. Vol. 4. Virginia Museum of Natural History, Memoir, pp. 1–57.
Vakhrameev, V.A., 1970. Range and paleoecology of Mesozoic conifers, the Cheirolepidiaceae. Paleontol. Zh. 1, 19–34.
Vakhrameev, V.A., 1978. The climates of the Northern Hemisphere in the cretaceous in the light of paleobotanical data. Paleontol. Zh. 2, 3–17.
Vakhrameev, V.A., 1980. *Classopollis* pollen as indicator of Jurassic and cretaceous climates. Sov. Geologiya 8, 48–56 (in Russian).
Vakhrameev, V.A., 1981. Pollen *Classopollis*: indicator of Jurassic and Cretaceous climates. The Palaeobotanist 28/29, 301–307.
Valero, I.C.R., 2014. Palynological evidence for the paleoenvironmental history of the Miocene Llanos Basin, Eastern Colombia. Seton Hall University Dissertations and Theses (ETDs). Paper 1956, p. 75 8 plates.
Vallati, P., 2013. A mid-cretaceous palynoflora with *Tucanopollis crisopolensis* from D-129 Formation, San Jorge Gulf Basin, Argentina. Rev. Brasil. Paleontol. 16 (2), 237–244.
Van der Hammen, T., 1963. A palynological study on the Quaternary of British Guiana. Leidse. Geol. Meded. 29, 125–180.
Van Konijnenburg-Van Cittert, J.H.A., 1971. *In situ* gymnosperm pollen from the Middle Jurassic of Yorkshire. Acta Bot. Neerlandica 20, 96.
Vaz, P.T., Rezende, N. das G.De.A. da M., Wanderley Filho, J.R., Travassos, W.A.S., 2007. Bacia do Parnaíba. Boletim de Geociências da PETROBRAS 15 (2), 253–263.
Villanueva-Amadoz, U., Pons, D., Diez, J.B., Ferrer, J., Sender, L.M., 2010. Angiosperm pollen grains of San just site (Escucha Formation) from the Albian of the Iberian Range (North-Eastern Spain). Rev. Palaeobot. Palynol. 162, 362–381.
Villanueva-Amadoz, U., Sender, L.M., Diez, J.B., Ferrer, J.J., Pons, D., 2014. A new isoetalean microsporophyll from the latest Albian of northeastern Spain: Diversity in the development and dispersal strategies of microspores. Acta Palaeontol. Pol. 59 (2), 479–490.
Volkheimer, W., Scafati, L., Melendi, D.L., 2007. Palynology of Danian warm climatic wetland in central northern Patagonia, Argentina. Revista Española de Micropaleontologia 39, 117–134.
Wang, Z., Wang, L., 1990. Late Early Triassic fossil plants from upper part of the Shiqianfeng Group in North China. Shanxi Geology 5 (2), 97–154.
Watson, L.; Dallwitz, M.J. 1992–2015. The families of flowering plants: descriptions, illustrations, identification, and information retrieval. Version: 11th May 2015. delta-intkey.com (last access on October, 23, 2017).
Wingate, F.H., 1980. Plant microfossils from the Denton Shale Member of the Bokchito Formation (lower cretaceous, Albian) in southern Oklahoma. Oklahoma Geol. Surv., Bull. 130, 1–93.
Zalán, P.V., 2007. Bacias de Bragança-Viseu, São Luís e Ilha Nova. Boletim de Geociências da PETROBRAS 15 (2), 341–345.
Zhang, M., Dai, S., Heimhofer, U., Wu, M., Wagn, Z., Pan, B., 2014. Palynological records from two cores in the Gongpoquan Basin, Central East Asia: evidence for floristic and climatic change during the late Jurassic to early cretaceous. Rev. Palaeobot. Palynol. 204, 1–17.
Ziembinska-Tworzydlo, M., 1974. Palynological characteristics of the Neogene of Western Poland. Acta Palaeontol. Pol. 19, 309–432.
Zobaa, M.K., El-Beialy, S.Y., El-Sheikh, H.A., El-Beshtawy, M.K., 2013. Jurassic–cretaceous palynomorphs, palynofacies, and petroleum potential of the Sharib-1X and Ghoroud-1X wells, north Western Desert, Egypt. J. Afr. Earth Sci. 78, 51–65.